Fisheries and Oceans Canada
Ecosystems and Oceans Science

Pêches et Océans Canada
Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Research Document 2015/050

Pacific Region

Habitat-Based Model and Stock-Recruit Productivity Estimates for Coho Salmon in Georgia Strait Mainland, Georgia Strait Vancouver Island and Lower Fraser Management Units

C.A.J. Noble[1], J. Korman[2] and R. Bocking[1]

[1]LGL Limited
9768 Second Street
Sidney, B.C., V8L 3Y8

[2]Ecometric Research
3560 W. 22nd Avenue
Vancouver, B.C., V6S 1J3

December 2015

Canada

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

© Her Majesty the Queen in Right of Canada, 2015

ISSN 1919-5044

Correct citation for this publication:

Noble, C.A.J., Korman J. and Bocking, R. 2015. Habitat-Based Model and Stock-Recruit Productivity Estimates for Coho Salmon in Georgia Strait Mainland, Georgia Strait Vancouver Island and Lower Fraser Management Units. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/050. x + 91 p.

TABLE OF CONTENTS

ABSTRACT viii

RÉSUMÉ ix

1. INTRODUCTION 1
   - 1.1. Predicting Smolt Abundance from Physical Habitat 2
   - 1.2. Study Area 3
   - 1.3. Management of Southern B.C. Coho Salmon 3

2. COHO SALMON PRODUCTION MODEL 4
   - 2.1. Data Sources And Treatments 4
     - 2.1.1. Coho Salmon Distributions 4
     - 2.1.2. Accessible Stream Length 4
     - 2.1.3. Stream Gradient 5
     - 2.1.4. Stream Order 6
     - 2.1.5. Smolt Data 6
     - 2.1.6. Smolts Produced Per Spawner 7
   - 2.2. Methods 7
     - 2.2.1. Smolt Regression Model 7
     - 2.2.2. Sensitivity Analyses 8
     - 2.2.3. Streams with Empirical Data 8

3. STOCK-RECRUITMENT 8
   - 3.1. Data Sources and treatment 9
     - 3.1.1. Exploitation Rate and Survival Data 9
     - 3.1.2. Spawner Data 9
     - 3.1.3. Hatchery Contribution Data 10
     - 3.1.4. Wild Spawner and Recruit Data 11
     - 3.1.5. Converting Adult Recruits to Smolt Recruits 11
   - 3.2. Methods 12
     - 3.2.1. Stock-Recruit Model Structure 12
     - 3.2.2. Parameter Estimation 13

4. RESULTS 14
   - 4.1. Habitat Model 14
   - 4.2. Stock-Recruit Analysis 15
     - 4.2.1. Wild Spawner and Recruit Estimates 15
     - 4.2.2. Stock-Recruit Results 15

5. SENSITIVITY ANALYSES 17
   - 5.1. Accessible Stream Length Determinations 17
   - 5.2. Smolts Per Spawner 17

6. DISCUSSION 18
   - 6.1. Habitat Capacity Model 18

6.1.1. Stream Length 18
6.1.2. Effect of Map Scale 18
6.1.3. Limits to Smolt Production 19
6.1.4. Required Number of Spawners 19
6.1.5. Sensitivity Analysis 20
6.1.6. Comparison of Estimated Spawners from Habitat Model vs. Infill Routine 21
6.2. Stock-Recruit Analysis and Benchmarks 21
7. CONCLUSIONS AND RECOMMENDATIONS 22
8. ACKNOWLEDGMENTS 22
9. LITERATURE CITED 23
10. TABLES 28
11. FIGURES 46
APPENDIX 1: ANNUAL COHO SALMON SMOLT DATA 58
APPENDIX 2: COHO SALMON-BEARING SALMON STREAMS 66
APPENDIX 3: STREAM-SPECIFIC ESTIMATES OF SMOLTS/SPAWNERS 78
APPENDIX 4: SEP RELEASE DATA 90

LIST OF TABLES

Table 1. Average smolt production, accessible length and years of data for 22 rivers within the EVI-GS, GSM, HS-BI and LFR CUs. 28

Table 2. Smolts produced per spawner where paired data is available. 29

Table 3. Exploitation rates and marine survival estimates of wild Coho Salmon from Black Creek and Myrtle River, 1983-2010. 30

Table 4. Indicator streams identified for escapement to the EVI-GS and GSM CUs, 1990-2013. 31

Table 5. Exploitation rate and marine survival estimates for hatchery-released enhanced fry in EVI-GS and GSM CUs, 1983-2011. 32

Table 6. Exploitation rate and marine survival estimates for hatchery-released smolts in the EVI-GS CU, 1983-2011. 33

Table 7. Predicted average number of Coho Salmon smolts required to seed available habitat and the required number of spawners to produce these smolts. 34

Table 8. Estimates of stream length, smolts produced and spawners required for the four largest contributing streams in each CU. 35

Table 9. Wild spawners and recruits for GSM and EVI-GS CUs, 1990-2013. 36

Table 10. Southern BC Coho Salmon benchmarks for EVI-GS and GSM CUs derived from the stock-recruit analysis. 39

Table 11. Deviance information criteria (DIC) comparing Beverton-Holt (BH) and Logistic Hockey Stick (LHS) models for each conservation unit (CU) and prior distribution of maximum recruitment (prCV). 41

Table 12. Estimated accessible stream length (m) over a range of gradient limits and minimum stream orders by conservation unit (CU). 42

Table 13. Percent change in required spawners with change in stream gradient limit and minimum stream order by conservation unit (CU). 43

Table 14. Percent change in required spawners across varying numbers of smolts produced per spawner. 44

Table 15. Comparison of stream lengths used to generate predictive regression (GIS Length) versus other data sources. 44

Table 16. Average spawners and 95% credible intervals (Lower CI, Upper CI) as estimated from the Habitat Model and the infilled nuSEDS escapement data, 1990-2013. 45

Table 17. Stock-recruit results for each CU and MU using the spawner-smolt recruit data and under assumptions of 1%, 2.5% and 5% marine survival and 0.6 prCV. 45

LIST OF FIGURES

Figure 1. Map of GSM, EVI-GS, HS-BI, BB, LFR and LILL CUs of interest and watersheds where Coho Salmon are known to spawn. 46

Figure 2. Schematic drawing of a stream of the 6th order, numbers indicate stream order........47

Figure 3. Natural log (LN) average smolt abundance as a function of LN accessible stream length (LN km) for all streams from CUs of interest where data was available....48

Figure 4. Hyper-distributions of stock productivity and carrying capacity (curved lines) based on a regional analysis of spawner-smolt recruit datasets (Korman and Tompkins 2014) compared to estimates from this study (vertical lines) by CU....49

Figure 5. Black Creek smolt-to-adult survival rates for Coho Salmon, 1990-2010. 50

Figure 6. Stock-recruit data for East Vancouver Island (EVI-GS) and Georgia Strait Mainland (GSM) Coho Salmon CUs. 51

Figure 7. Stock-recruitment relationships for the East Vancouver Island (EVI-GS) Coho Salmon CU based on a Beverton-Holt model fit to spawner-adult recruit (left column) and spawner-smolt recruit (right column) data sets....52

Figure 8. Stock-recruitment relationships for the East Vancouver Island (EVI-GS) Coho Salmon CU based on a Logistic Hockey Stick model fit to spawner-adult recruit (left column) and spawner-smolt recruit (right column) data sets. 53

Figure 9. Stock-recruitment relationships for the Georgia Strait Mainland (GSM) Coho Salmon CU based on a Beverton-Holt model fit to spawner-adult recruit (left column) and spawner-smolt recruit (right column) data sets....54

Figure 10. Stock-recruitment relationships for the Georgia Strait Mainland (GSM) Coho Salmon CU based on a Logistic Hockey Stick model fit to spawner-adult recruit (left column) and spawner-smolt recruit (right column) data sets. 55

Figure 11. Comparison of fits of Beverton-Holt (BH, solid black line) and Logistic Hockey Stick (LHS, red dashed line) models to a regional spawner-smolt stock-recruit data set (1941 - 2004) (reproduced from results in Korman and Tompkins 2014). 56

Figure 12. Spawner-smolt recruit data set for Black Creek, 1990-2010. 57

LIST OF APPENDIX TABLES

Table A1. Annual Coho Salmon smolt data and sources by brood year. 58

Table A2. Watershed area, stream order and accessible length by gradient limit for all Coho Salmon bearing salmon streams within the GSM, LFR, LILL, EVI-GS, HS-BI and BB CUs. 66

Table A3. Stream-specific estimates of average smolt yield and spawners required to produce estimated average smolts for each watershed in each CU. 78

Table A4. SEP release data by CU, life stage and brood year, 1990-2011....90

ABSTRACT

Identifying biological reference points or benchmarks for management of Coho Salmon is a critical component of the Wild Salmon Policy, and key to sustainable fishery management; yet data and budget restrictions limit the use of traditional stock recruit methods to identify benchmarks. Here, we combine a habitat-based model and Bayesian stock-recruit and stock-smolt analysis to estimate average CU smolt production and the number of spawners required to achieve this, as well as stock productivity parameters and three potential benchmarks (Umsy, Smsy and Sgen) for wild (non-enhanced) Coho Salmon populations. Stock recruit analyses were conducted using both Beverton-Holt and Logistic Hockey Stick models and spawner-to-smolt and spawner-to-recruit data sets. Stream length accessible to Coho Salmon was determined from terrain resource inventory maps (TRIM) using GIS and maps at 1:20,000 scale. Stream order, gradient and known barriers were used to define the accessible length of stream. The number of smolts per kilometer was derived using a log-linear predictive regression of smolt yield given stream length for 22 streams within the CUs of interest. Average estimated smolt production and the number of spawners required to produce the average number of smolts for each CU were calculated respectively as 1,603,226 and 49,422 (EVI-GS); 395,603 and 11,968 (GSM); 751,868 and 22,784 (HS-BI); 1,484,479 and 46,005 (LFR); 910,977 and 27,605 (LILL); and 608,082 and 18,427 (BB). Estimated average smolt production and spawners for each MU were calculated respectively as 1,147,471 and 34,752 (GSM); 3,003,538 and 92,037 (LFR); and 1,603,226 and 49,422 (GS-VI). Results of the Habitat Model are dependent on the amount of habitat available, particularly as it applies to stream order, and to the number of smolts produced per spawner. The Logistic Hockey Stick stock-recruit model estimates that at an assumed future marine survival rate of 2.5%, harvest rates of approximately 35-40% will produce MSY for EVI-GS and GSM CUs; however, at 1.0% survival, harvest rates to produce MSY drop to 1-4% for EVI-GS and GSM CUs, a level more in line with current management practices. While we model, and provide, estimates of Sgen and Smsy, we abstain from recommending these benchmarks due to implementation challenges relating to the fact that escapement is not monitored completely to determine if the benchmark was met and because it requires a reliable pre-season forecast of abundance to determine how much catch to take to end up at Sgen or Smsy. The results of the stock-recruit analysis are highly dependent on marine survival estimates. Data deficiencies prevented stock recruit analyses to be completed on all other CUs, which resulted in no stock recruit analysis conducted on the GSM and LFR MUs.

Modèle fondé sur l'habitat et estimations de la productivité stock-recrutement du saumon coho dans les zones de gestion du détroit de Georgie (continent), du détroit de Georgie (île de Vancouver) et du bas Fraser

RÉSUMÉ

La détermination de points de référence biologiques ou d'autres points de référence dans le cadre de la gestion du saumon coho est une étape clé de la Politique concernant le saumon sauvage. Il s'agit d'un élément essentiel dans la gestion de la pêche durable. Pourtant, les données disponibles et les restrictions budgétaires limitent l'utilisation de méthodes traditionnelles basées sur la relation stock-recrutement pour déterminer les points de référence. Ici, nous associons un modèle fondé sur l'habitat à une analyse bayésienne stock-recrutement et stock-saumoneaux dans le but d'estimer la production moyenne de saumoneaux des unités de conservation ainsi que le nombre de reproducteurs nécessaires pour atteindre cet objectif. Ces éléments permettent également de générer des estimations des paramètres de productivité du stock et trois points de référence possibles (URMS, SRMS et Sgén) pour les populations de saumon coho sauvages (non mis en valeur). Des analyses stock-recrutement ont été effectuées à l'aide des modèles de Beverton-Holt et de la courbe logistique en « bâton de hockey », ainsi qu'à l'aide des ensembles de données sur le rapport reproducteurs-saumoneaux et reproducteurs-recrutement. La longueur de cours d'eau accessible au saumon coho a été déterminée à partir de cartes d'inventaire des ressources sur le terrain (terrain resource inventory maps [TRIM]) basées sur un SIG et sur des cartes d'une échelle 1:20 000. L'ordre, la pente et les obstacles connus des cours d'eau ont été utilisés pour en établir la longueur accessible. Le nombre de saumoneaux par kilomètre a été calculé par régression linéaire logarithmique prédictive du rendement de saumoneaux à partir de la longueur de 22 cours d'eau situés dans les unités de conservation d'intérêt. La moyenne estimée de la production de saumoneaux et le nombre de reproducteurs requis pour produire le nombre moyen de saumoneaux pour chaque unité de conservation ont été calculés, et les valeurs respectives obtenues sont les suivantes : 1 603 226 et 49 422 (est de l'île de Vancouver, détroit de Georgie); 395 603 et 11 968 (partie continentale du détroit de Georgie); 751 868 et 22 784 (baie Howe et bras de mer Burrard); 1 484 479 et 46 005 (bas Fraser); 910 977 et 27 605 (Lillooet); 608 082 et 18 427 (baie Boundary). Les estimations de la production moyenne de saumoneaux et du nombre de reproducteurs requis pour chaque zone de gestion sont respectivement les suivantes : 1 147 471 et 34 752 (partie continentale du détroit de Georgie); 3 003 538 et 92 037 (bas Fraser); 1 603 226 et 49 422 (détroit de Georgie, île de Vancouver). Les résultats du modèle de l'habitat dépendent de la surface de l'habitat accessible, notamment concernant l'ordre des cours d'eau, et du nombre de saumoneaux produits par reproducteur. Les estimations obtenues à partir du modèle stock-recrutement représenté par une courbe logistique en « bâton de hockey » indiquent qu'avec un futur taux de survie en mer de 2,5 %, les taux de récolte d'environ 35 à 40 % produisent un rendement maximal soutenu (RMS) dans les unités de conservation de l'est de l'île de Vancouver (détroit de Georgie) et de la partie continentale du détroit de Georgie. Toutefois, avec un taux de survie de 1,0 %, les taux de récolte engendrent une baisse du RMS, qui passe à une valeur comprise entre 1 et 4 % dans les unités de conservation de l'est de l'île de Vancouver (détroit de Georgie) et de la partie continentale du détroit de Georgie, un niveau plus conforme aux pratiques de gestion actuelles. Bien que nous effectuions des modélisations et fournissions des estimations de la valeur SRMS et Sgén, nous nous abstenons de recommander ces points de référence en raison des difficultés de mise en œuvre qui proviennent du fait que les échappées ne sont pas totalement surveillées et ne permettent donc pas de déterminer si le point de référence a été atteint, et parce qu'il est indispensable de disposer d'une prévision fiable d'avant-saison de l'abondance

pour déterminer la quantité de prises nécessaires pour atteindre les valeurs SRMS et Sgén. Les résultats de l'analyse stock-recrutement dépendent grandement des estimations du taux de survie en mer. L'absence de données a empêché de réaliser les analyses stock-recrutement sur toutes les autres unités de conservation. Aucune analyse stock-recrutement n'a donc pu être réalisée dans les zones de gestion de la partie continentale du détroit de Georgie et du bas Fraser.

1. INTRODUCTION

The need to establish escapement goals based on stock-specific productive capacity is fundamental to wild stock conservation and sustainability of Coho Salmon (*Oncorhynchus kisutch*) fisheries in British Columbia. Action step 1.2 of Canada's Wild Salmon Policy (WSP) states that benchmarks are to be developed for each salmon conservation unit (CU), which will represent biological status and will be based on abundance and distribution of spawners, or proxies thereof (DFO 2005). Here, we estimate Coho Salmon productive capacity using stream-specific smolt production averages, stream-specific production of smolts per spawner; and GIS estimates of available habitat for six CUs and their component Pacific Salmon Commission Management Units (MUs): Georgia Strait Mainland CU (GSM) (MU: Strait of Georgia Mainland), East Vancouver Island – Georgia Strait CU (EVI-GS) (MU: Strait of Georgia Vancouver Island), Howe Sound – Burrard Inlet CU (HS-BI) (MU: Strait of Georgia Mainland), Lower Fraser CU (LFR) (MU: Lower Fraser), Lillooet River CU (LILL) (MU: Lower Fraser), and Boundary Bay CU (MU: Lower Fraser). Hereafter we will refer to CU nomenclature. All data and results are provided at the CU level unless stated otherwise.

Modern salmon management policies also require the development of salmon escapement goals or reference points, and that they are based on some measure of the ability of the stream (and marine) ecosystem to produce salmon. However, estimating the productive capacity for each Coho Salmon stock within a given unit of interest would be challenging due to technical, financial and data deficiencies. The use of a traditional stock-recruitment approach at the stock level to estimate productive capacity for Coho Salmon is inherently difficult due to a lack of direct estimates of juvenile Coho Salmon production, catch estimates and spawner abundance on an annual stock-specific basis. Hence, for virtually all Coho Salmon streams in Southern British Columbia, there remains uncertainty regarding the appropriate escapement goals for Coho Salmon.

Canada's Wild Salmon Policy (DFO 2005) stipulates that management of salmon be based on a conservation unit (CU) which is an aggregate of salmon stocks/populations of similar life history, geographical location and genetics. The establishment of CU-specific escapement goals for Coho Salmon is therefore necessary, as management of fisheries and monitoring of population status will be assessed relative to these goals. While productive capacity estimates may serve as a basis for the development of Wild Salmon Policy benchmarks, this paper does not make such a recommendation. This is better done as part of setting stock management and fishery management objectives.

Furthermore, managing and monitoring salmon at the CU level is also in keeping with the management methods currently used for the many mixed-stock Coho Salmon fisheries in British Columbia. For example, under the current abundance based management (ABM) system, exploitation of Coho Salmon in CUs of low abundance is constrained to facilitate recovery. Exploitation of the Interior Fraser CU is constrained to a level not to exceed 3%. This restriction has positively affected the co-migrating Georgia Basin CUs which have been beneficiaries of this reduced exploitation.

Habitat capacity modelling provides an alternative to modelling spawner-recruit relationships for determining productive capacity for Coho Salmon. Numerous authors have investigated relationships between fish abundance in streams (number of spawners, smolt yield, fry density, etc.) and physical habitat variables (e.g., Baranski 1989, Reeves et al. 1989, Holtby et al. 1990, Marshall and Britton 1990, Jowett 1992, Nickelson et al. 1992, Bradford et al. 1997, Rosenfeld et al. 2000, Pess et al. 2002). Faush et al. (1988) reviewed 99 models that predict the abundance of stream fish from habitat variables. Water temperature, flow, depth, velocity, water quality, food availability, channel characteristics, and watershed characteristics have all been considered in models (Jowett 1992). These multivariate models require intensive amounts of data for specific habitat characteristics and may or may not be suitable beyond specific species, streams or geographic regions. For the majority of the nearly 2,600 spawning populations of Coho Salmon in British Columbia (Slaney et al. 1996), these data simply do not exist and would be too costly to collect.

Traditional stock assessment approaches have used either information about the capacity of the environment (e.g. Blackett, 1979) or the observed relationship between stock size and recruitment (e.g. Minard and Meacham, 1987). Both approaches, however, have drawbacks, including: difficulty quantifying suitable habitat (environment based); and counting errors, scarcity of data and high environmentally-driven variability (stock-recruit) (Adkison and Peterman, 1996). Geiger and Koenings (1991) applied a Bayesian approach to traditional stock-recruit methods that incorporated both environmental and stock-recruit data in estimating Chilkoot Lake (Alaska) Sockeye Salmon stock-recruit relationships. Adkison and Peterman (1996) agree that this approach can be a substantial improvement over traditional stock-recruit methods, however, they caution that failure to include all reasonable stock-recruit relationships in this type of analysis can lead to overestimation in the certainty of results.

1.1. PREDICTING SMOLT ABUNDANCE FROM PHYSICAL HABITAT

Studies have shown that carrying capacity of a stream is related to physical attributes of the stream (Marshall and Britton 1990). Burns (1971), Mason and Chapman (1965) and Chapman (1965) all found that stream surface area provided the best correlation with absolute biomass (all species), production and density, respectively. Lister (1968) found little difference in Coho Salmon smolt yield per unit of stream length in five British Columbia streams and concluded that 2,484 smolts per kilometre was a useful biostandard for determining yield. Mason (1974) found that Coho Salmon fry biomass could be increased substantially by augmenting the food supply with daily feedings of euphausiids. However, smolt yield did not increase beyond expected natural levels.

Bocking and Peacock (2004) developed a habitat-based model to estimate the number of spawners required to seed available habitat and produce the mean number of Coho Salmon smolts in British Columbia Area 3 (Nass Area) streams. Estimating smolt yield based on the linear distance of available freshwater rearing habitat within a stream or watershed has been suggested by several authors (Holtby et al. 1990, Marshall and Britton 1990, Bradford et al. 1997, Nickelson 1998, Rosenfield et al. 2000 and Bocking et al. 2005[1]). Logistic regression models have also successfully been used to predict upstream extent of fish occurrence in Washington State (Fransen et al. 2006). Bocking and Peacock (2004) identify a number of key assumptions in their approach that are applicable to our model:

(1) stream length is a valid surrogate for the limiting habitat available to Coho Salmon pre-smolts and ultimately limits the amount of smolts produced by the system;

(2) the production bottle neck that occurs during the parr-smolt stage of freshwater life is primarily a function of available suitable riverine habitat for pre-smolts; and

(3) ocean type Coho Salmon play a limited role in productivity. Further to these, we assume that smolt production, as provided in the regional empirical dataset, reflects production

---

[1] Bocking, R.C., C.K. Parken, and D.Y. Atagi. 2005. Nass River steelhead habitat capability production model and preliminary escapement goals. Unpublished report for Ministry of Water, Land and Air Protection, Smithers, British Columbia.

across high and low spawner abundances, and therefore represents the average number of smolts produced per kilometer of habitat. Bocking et al. (2005)[1] provide a similar habitat production model for Steelhead in the Nass River and for Coho Salmon on Haida Gwaii.

Through estimating Coho Salmon smolt production based on length of available habitat for each of the six CUs and using regional, empirical estimates of smolts produced per spawner, one can estimate the required number of spawners needed to produce the average number of smolts. The number of spawners required for each CU to yield average smolt production is therefore the end goal of the habitat model discussed here. As Coho Salmon CUs are nested within a respective Management Unit, CU specific smolt production estimates can be aggregated to their respective MU.

1.2. STUDY AREA

The study area for this work includes all streams where Coho Salmon presence is confirmed within the Georgia Strait Mainland, East Coast Vancouver Island – Georgia Strait, Howe Sound – Burrard Inlet, Lower Fraser, Boundary Bay and Lillooet River CUs. The Jordan River marks the most south-western boundary and is located about 70 km West of Victoria, while Menzies and Mohun Creek near Campbell River mark the most north-western boundary. On the Georgia Strait mainland side, the Quatam River marks the northern most boundary, and all streams and rivers south of here to Noons creek (Burrard Inlet) are included (Figure 1). Lower Fraser streams include all those upstream to the Chilliwack area, those in the Pitt River Watershed, and those up to Harrsion Lake (Figure 1). Lillooet CU streams include all those upstream of Harrison Lake, while the Boundary Bay CU is comprised of four watersheds located between the Fraser River and the U.S./Canadian border (Figure 1).

1.3. MANAGEMENT OF SOUTHERN B.C. COHO SALMON

Management of Coho Salmon fisheries in southern B.C. is formally described and agreed to in the Pacific Salmon Treaty. As of 2002, the fishery has been managed on an abundance-based system (ABM) which will continue to 2018. Under the ABM, exploitation of CUs of low abundance are constrained in hopes of facilitating recovery. The Georgia Strait – Mainland, East Vancouver Island – Georgia Strait Mainland, and Interior Fraser CUs are identified as CUs where harvest is constrained (DFO 2011), and 2013 Canadian fishery exploitation rates were not to exceed 3% on the Interior Fraser CU. Where abundance and health of wild Coho Salmon is high enough to facilitate harvest, fishing mortality limits are developed on an annual basis and fisheries are managed to not exceed the defined limit. For detailed text and formulae on Southern B.C. Coho Salmon management, we refer the reader to the PSC website.

Within Southern B.C., a number of Coho Salmon smolt enumeration programs operate for the purpose of monitoring production, exploitation and marine survival of wild smolts, survival and exploitation of enhanced (hatchery) origin smolts, and for assessing production on waters influenced by hydroelectric projects. The total number of stream years and CUs in which smolt enumeration programs occurred are: 167 (EVI-GS), 16 (HS-BI), 17 (GSM) and 47 (LFR). Not all streams have been monitored annually, nor have all streams been monitored from the same start year.

Wild stocks of Coho Salmon in Southern B.C. are supplemented through DFO's Salmon Enhancement Program (SEP) which is designed to support vulnerable stocks and to provide harvest opportunities through sustainable fisheries. A complete list of enhanced rivers and their respective brood releases can be found in the 2011 Southern Salmon IFMP (DFO 2011).

Annual SEP releases have been upwards of 11 million fish (1987, EVI-GS), but more recently (since 2004) average around 3.5 million (EVI-GS) and 37,000 (GSM).

Despite the large number of Coho Salmon spawning systems within the study area and relatively high number of fenced and enhanced systems, a habitat-based approach to quantifying the productive capacity for Coho Salmon was determined to be the most appropriate approach to establishing escapement reference points for reasons previously discussed. The habitat-based approach to deriving these system specific productivity estimates and total area spawner requirements are described in this paper as the Georgia Strait – East Vancouver Island – Mainland Coho Salmon Production Model (and also referred to in this paper as the Habitat Model).

2. COHO SALMON PRODUCTION MODEL

Since the 1950s, annual surveys of Coho Salmon escapement by DFO have identified a total of 365 sites within our study area where Coho Salmon spawn in the EVI-GS CU (107), GSM CU (55), HS-BI CU (68), LFR (115), LILL (17), and the BB (4) CUs. While we have included the habitat of all 365 sites in our model, some sites (e.g. side-channels, sloughs and spawning channels) have been aggregated into a larger river/watershed such that a total of 313 streams are herein identified and modeled. Therefore, some of the names of these sites identified by DFO will not be specifically mentioned here. Coho Salmon escapements vary significantly among all streams, and it is possible that not all Coho Salmon-bearing streams are represented in the Fisheries and Oceans database (nuSEDS). Any omission of streams in the nuSEDS database inhabited by Coho Salmon is likely to be insignificant.

The Georgia Strait – East Vancouver Island – Mainland Coho Salmon Production Model is a habitat-based model that predicts average smolt abundance for each stream and the number of spawners that are required to produce the average smolt abundance (S_{avg}), using the length of stream available for Coho Salmon rearing as the predictor variable. The model first calculates the total length of stream that is accessible for Coho Salmon using stream gradient, known barriers and stream order (Strahler 1957). A relationship between smolt yield and stream length was then developed using a log-linear model to predict smolt yield from stream length using smolt production data from a total of 22 streams monitored for wild smolt production in the EVI-GS (15 streams), GSM (2 streams), HS-BI (2 streams) and LFR (3 streams) CUs. Stream length used to generate this predictive model was that estimated through GIS and includes ditches, tributaries, side channels, manmade habitat, etc., and therefore may differ from third party estimates. The model does not directly account for variability in quality of habitat between rivers.

2.1. DATA SOURCES AND TREATMENTS

2.1.1. Coho Salmon Distributions

Fisheries and Oceans Canada provided a list of all known Coho Salmon bearing streams within each of the six CUs of interest (Figure 1) and a total of 365 streams were identified. Coho Salmon streams within all CUs are likely well accounted for due to the historic and extensive coverage of the area by DFO personnel and/or contractors. Therefore, all known Coho Salmon producing streams of order 1-7 with Fisheries and Oceans records of Coho Salmon escapement were included in the analysis.

2.1.2. Accessible Stream Length

In a particular stream or tributary, available Coho Salmon habitat is restricted by both physical limitations (barriers, gradient, and discharge, water quality (dissolved oxygen, turbidity, and temperature)) and evolutionary distribution factors. Suitable spawning and rearing habitat can remain inaccessible due to waterfalls, debris jams, excessive water velocities, man-made barriers, etc. which may impede fish access seasonally, annually, inter-annually or permanently. However, assessing whether or not an obstruction is a barrier is not easy. Falls that are insurmountable at one time of the year may be passed at other times under different flows (Bjorn and Reiser 1991). Powers and Orsborn (1985) reported that the ability of salmonids to pass over barriers is dependent on the swimming velocity of adult fish, the horizontal and vertical distances to be jumped, and the angle to the top of the barrier. The pool depth to height ratio is also important (Stuart 1962). Bjorn and Reiser (1991) determined a maximum jumping height for Coho Salmon of 2.2 m under optimal conditions. Therefore, where a barrier equal to or greater than 2.0 m existed, the Habitat Model considered this a complete barrier to migration. Man-made structures (culverts, for example) are assumed passable, unless they have been documented otherwise. Furthermore, any gradient in excess of 100% (45°) for longer than 10 metres was also identified as a barrier to Coho Salmon migration.

All available information on barriers and gradient within each watershed was used to restrict Coho Salmon access in systems. The sources of information on barriers included Fisheries Information Summary System data (BC Ministry of Environment, 2014), and Aquatic Biophysical Maps (MOE 1977). Where barriers were identified, but were without associated metrics (height, type, etc.), all efforts were made by the authors to ascertain the necessary information. This was done through discussions with knowledgeable local First Nations representatives (Sliammon, Sechelt), representatives of local stream keeping groups (Squamish, Peninsula Streams, Bowen Island, etc.), hatchery representatives (Qualicum, Nanaimo, Port Moody, Seymour, Chapman Creek, etc.), dam operators/owners, Google Earth and available online documentation (Environmental Assessments for Run of River Hydropower projects, for example). The total accessible stream length within each tributary was calculated from digital TRIM files (1:20,000 scale) using ARCINFO (ESRI 2010) and stratified according to gradient and stream order. Where lakes were present within the network of accessible stream, the length of centre lines connecting accessible lake tributaries to the lake outlet was included in the total length calculation. This had the net effect of including a portion of the lake something less than the perimeter as suitable habitat for juvenile Coho Salmon.

Habitat in streams greater than or equal to an order of 1 were included, such that when calculating available habitat, a stream of order 6 would include accessible habitat in all orders of that stream 1 – 6. This differs from Bocking and Peacock (2004) which assumed that Coho Salmon would not occupy stream habitats more than two stream orders distance from the main stem due to removal of this habitat during winter due to ice/freeze up. Following discussions with DFO biologists, it was agreed that rivers in the current area of interest are less prone to ice/freeze up and were therefore included in the model presented here.

2.1.3. Stream Gradient

Pess et al. (2002) found that Coho Salmon spawner abundance was correlated with stream gradient in the Snohomish River, Washington. Coho Salmon have been reported to occur in stream segments with gradients ranging from one to ten percent, with the greatest densities occurring in the lower gradients. Higher gradient areas are dominated by larger substrate and lack the pool habitat favoured by Coho Salmon for rearing (Bisson et al. 1982). The Georgia Strait – East Vancouver Island – Mainland Coho Salmon Production Model assumed that stream gradients over 8% were not utilized by Coho Salmon parr or pre-smolts for rearing and that all gradients below 8% had similar density of Coho Salmon. ARCINFO and a gradient analysis program were used to calculate the accessible length of stream within each watershed. For sensitivity analyses, accessible area was determined for upper gradient limits of 2%, 4%, 6% and 8%.

2.1.4. Stream Order

Stream orders were determined using a method developed by Horton (1945) and later modified by Strahler (1957) and were determined from the BC TRIM digital mapping (1:20,000 scale).

Streams in the study area had stream orders from 1-7. The analysis included all accessible lengths for stream orders of 1 or greater, and is schematically illustrated in Figure 2.

2.1.5. Smolt Data

DFO maintains an extensive data time series of Coho Salmon smolt production for 37 different streams in 15 different DFO Statistical Areas around Vancouver Island and the Georgia Strait. Only one of these streams (Carnation Creek) has been monitored annually since 1971, and two have only one observation (Millstream and Mud Bay). Further to these estimates, BC Hydro and Metro Vancouver operate smolt traps at various locations in the Greater Vancouver Regional District (GVRD) (BC Hydro 2011; 2012a; 2012b; Metro Vancouver 2012), and they made this data accessible to us. To generate mean smolt yield, we selected only streams which had a minimum of 4 annual estimates of wild smolt production and were located in the CUs of interest. A minimum of four years of data was selected in order to both allow a reasonable number of streams to be included, while also providing some level of variation around smolt production. Following our selection process, a total of 22 streams (247 annual estimates) were used in our analyses (Appendix 1), a summary of which are provided in Table *1*.

Smolt data provided by DFO includes production from all available upstream habitat (i.e. enumeration sites operate at, or very near to, the river's mouth), with the exception of Cowichan River, data from which is an index of production from habitat in, and above, the lake. However, all non-DFO smolt data estimates come from a site some distance upriver of the mouth. For rivers where enumeration did not occur at the mouth (Cowichan River, South Alouette, Cheakamus, Coquitlam and Seymour), we assumed Coho Salmon production was equal throughout the watershed and pro-rated available smolt data to represent the entire accessible length. Therefore, for these rivers, estimates of smolt production are different (larger) than that presented in the source document.

Smolt data is available from a wide variety of streams within our study area, and represent four of the six CUs. Streams with smolt data are from very different environments, and are representative of the highly diverse geographical area of our study. For example, Black Creek is a highly ditched river which drains productive agricultural lands on the East Coast of Vancouver Island, while Salmon River drains a large, urbanized watershed, in the GVRD. Quinsam River has extensive out-planting of enhanced origin salmon and the Cheakamus has been the recipient of extensive habitat improvements over the years. Some systems are lake-headed, but dammed (South Alouette River, Coquitlam River, Cheakamus River), while others (Cowichan River) are lake-headed, but remain accessible. Short (Millard, Kirby, Bush, etc.) and long streams (Cowichan and Salmon River) are also represented (Table 1). These streams broadly represent the diversity of environments found within the six CUs, and are therefore good candidates for generating a region-wide predictive regression model.

2.1.5.1. Smolt Data Caveats

Not all available smolt data were included in our model. Two additional streams within our study area have smolt estimates available, and meet the minimum criteria for inclusion, but were excluded for the following reasons: Sakinaw Lake (GSM) has ten years of smolt data, however upon review of this data with DFO, it was agreed that it should not be included due to the difficulty (inability) to definitively identify the habitat from which the smolts were produced; and Capilano River also has smolt data available, however it is a fully enhanced system, and therefore data is not relevant to our work.

Cheakamus River smolt production in 2006 was excluded from analyses as this was the year where fish were affected by a severe and debilitating caustic soda spill in 2005. The Seymour River underwent extensive nutrient loading from 2003 – 2011 for the purpose of elevating productive capacity to its natural, historic (pre-dam) level. While concerns were raised by DFO biologists with respect to this, the evidence was not strong enough to recommend or support the exclusion of this data from analysis. Upon review of Simms Creek data by DFO biologists, it was found that only four years of smolt counts could be used due to the release of enhanced Coho Salmon in many years, but no differentiation of enhanced smolt and wild smolt production at the fence. Therefore, we were only able to use Simms Creek data from brood year 2001 – 2004 which are the years where no enhancement occurred, and all production is therefore wild. Further to these caveats, the Cheakamus River, South Alouette and Coquitlam River enumeration programs were primarily designed to assess the effects of different flow regimes (from hydro dams) upon salmonid production. In all cases, these evaluations of flow regimes are ongoing, and assumed to have negligible effects on production.

2.1.6. Smolts Produced Per Spawner

Determining the number of spawners required to produce a given average number of smolts involved back-calculating from the smolt estimate to spawners using an estimate of smolts produced per spawner (smolts/spawner). For each stream in our smolt dataset, we paired annual estimates of smolt production in year *y* with escapement in year *y-2* for streams where escapement data quality was classified as Type IV or better. We excluded streams where fewer than four paired smolt per spawner data points were available and were thus able to pair a total of 85 years of data across nine rivers (Table 2). While estimates of smolts/spawner were found to be variable (5 – 150), the average (38) is similar to the 85 smolts produced per female (or 42.5 smolts/spawner) in coastal Coho Salmon streams as estimated by Bradford et al. (2000), but much less than the 104 smolts/spawner estimated by Korman and Tompkins (2014). When back-calculating the number of spawners necessary to produce the modelled number of smolts, we therefore assumed that for every 38 smolts, one spawning adult was required. This direct estimate of smolts per spawner allowed us to eliminate assumptions and uncertainties around egg – fry and fry – smolt survival, as well as eliminating the need to estimate fecundity and sex ratio. This is unlike previous habitat capacity models (e.g., Bocking and Peacock 2004) or a previous version of this model.

2.2. METHODS

2.2.1. Smolt Regression Model

The smolt regression model used a local geographic data set to determine the smolt yield per kilometre of stream. Annual yield of Coho Salmon smolts and the associated accessible stream length (GIS estimate) were compiled for all 22 streams in the study area where data was available (Table 1). Coho Salmon smolt yield was calculated for streams with four or more annual estimates. From this data, a predictive regression model was developed (Figure 3).

The predictive regression used for the generating smolt estimates for our CUs was:

$$\ln(\text{smolt yield}) = 6.0966 + 1.0997 * \ln(\text{stream length}) \qquad \text{Equation (1)}$$

$$R^2 = 0.6745$$

Predictions of log-transformed smolt yield and the associated variance were then made given the stream length using the well-known predictive regression functions (e.g., Draper and Smith 1981). The arithmetic expectation and variance for smolt yield was next calculated assuming a log-normal distribution using:

$$E[Y] = \exp\{\hat{\mu} + \hat{\sigma}^2 / 2\}$$ Equation (2)

and

$$Var(Y) = \exp\{2\hat{\mu} + \hat{\sigma}^2\}(\exp\{\hat{\sigma}^2\} - 1)$$ Equation (3)

where $\hat{\mu}$ is the mean and $\hat{\sigma}^2$ is the variance of the logged transformed predictions (Johnson and Kotz 1970). Assuming the stream predictions are independent, the mean for the CU is the sum of the mean of the component streams. Thus, the predicted means were summed for each watershed within each CU, and also for each CU. The variance terms for each component stream can be similarly summed to get area-wide variance values. The summed mean and variance estimates can be regarded as normally distributed according to the central limit theorem where sample size is sufficiently large (greater than 15). Due to the small number of component streams in the Boundary Bay CU, variance estimates are not available for this CU.

The Habitat Model carries with it the critical assumption that stream length of stream orders of 1 or greater (at 1:20,000 scale) is a valid surrogate measure for the limiting habitat available to Coho Salmon pre-smolts and ultimately limits the amount of smolts produced by the system. This assumption is supported by the fact that there is downstream movement of fry during fall and winter freshets to occupy lower areas of streams as pre-smolts (Cederholm and Reid 1987). A portion of Coho Salmon fry migrating downstream may also exit the freshwater environment either passively due to environmental clues (e.g. flooding, freeze-up) or actively due to territorial displacement (Bilby and Bisson 1987, Hartman et al. 1981). The number of smolts emigrating from the stream after one or more years of freshwater residency is therefore assumed to be a function of the number of fry that survive to become parr in their first year of freshwater residency. The limiting factor for maximizing steelhead production is often cited as the availability of suitable habitat at the parr stage (Ptolemy et al. 2004).

The Habitat Model also assumes then that this production bottleneck occurring during the parr-smolt stage of freshwater life for Coho Salmon is primarily a function of available suitable riverine habitat for yearling Coho Salmon (hereafter referred to as pre-smolts). To the authors' knowledge, there have been no attempts to quantify any relationship between the amount of late summer or winter rearing habitat available to Coho Salmon pre-smolts and stream length. However, Sharma and Hilborn (2001) did find that lower valley slopes, lower stream gradients, and pool and pond densities were correlated with higher smolt densities.

2.2.2. Sensitivity Analyses

Sensitivity analyses were performed on a number of model parameters to explore the sensitivity of predicted smolt yield and required spawner numbers to those parameters. The parameters tested were gradient barrier criteria, stream order, and smolts produced per spawner.

2.2.3. Streams with Empirical Data

For streams where empirical data exists for average smolt production (Table 1) and/or smolts per spawner (Table 2), this data was used to estimate productivity of that specific stream, rather than estimates from the log-linear predictive regression model.

3. STOCK-RECRUITMENT

A number of challenges exist when trying to estimate stock-recruit parameters of wild fish in CUs that are heavily enhanced and that have significant gaps in the escapement monitoring record. Parken et al. (unpublished manuscript)[2] provide methods on how to deal with these challenges. Herein we summarize the methods as they apply to our CUs of interest.

Due to time and personnel constraints at DFO, available data from LFR, HS-BI, and LILL CUs were not reviewed, and there was no need to review the BB data as it is insufficient for any type of stock-recruit analysis. Consequently, all stock-recruit analyses apply only to adult natural spawners (excluding Jacks) in the EVI-GS and GSM CUs.

3.1. DATA SOURCES AND TREATMENT

3.1.1. Exploitation Rate and Survival Data

Exploitation rates (ER) and survival (smolt to adult) of Southern BC Coho Salmon are estimated for ten streams in the region (7 hatchery and 3 wild). Of these, 3 hatchery streams (Big Qualicum, Goldstream, Quinsam) and 2 wild streams (Black Creek and Myrtle Creek) are within the EVI-GS and GSM CU. Black Creek exploitation rate data is used for both CUs. Independent survival estimates are available for some years for Myrtle Creek Coho Salmon (wild) (Table 3).

Exploitation rates of hatchery Coho Salmon have been estimated using two different approaches since monitoring began. Exploitation rate estimates prior to brood year 1994 and for brood year 2000 to present was estimated using data from the Mark Recovery Program (MRP), while an effort based approach (commonly referred to as the Domestic Model) (Simpson et al. 2004) was used for brood years 1995 – 1999 when there were no Coho Salmon fisheries and mark selective fisheries had not yet started. The MRP estimates are based on analysis of estimated recoveries of CWTs in fisheries and escapement for specific indicator stocks (Quinsam River (EVI-GS) and Big Qualicum (EVI-GS). Exploitation rates of wild Coho Salmon were also estimated using the (effort-based) Domestic Model.

Survival of Coho Salmon from smolt to adult (wild and enhanced) is estimated via a coded-wire tagging (CWT) program, whereby out-migrating smolts are tagged at the enumeration site (wild), or hatchery (enhanced). Wild origin smolts are not marked (adipose clipped) as different exploitation rules apply to enhanced origin Coho Salmon versus wild Coho Salmon, and having a mark distinguishes which rules apply to a caught fish. Upon return to the indicator streams, adults are sampled directly for the presence/absence of a CWT. Once harvest is estimated, survival can be estimated for wild and enhanced origin Coho Salmon stocks as both the total number of out-migrating smolts is known, as are the total number of harvested and escaped adult fish.

3.1.2. Spawner Data

DFO annually assesses escapement to some streams in most CUs, providing an estimate of total returns (hatchery and natural origin fish returning to their natal stream). Total return data was provided by DFO via the New Salmon Escapement Database System (nuSEDS) (DFO 2014). Methods vary from high quality "fixed site census" and Area Under the Curve (AUC) estimates to lower quality "peak live + dead" estimates, as well as many other types, including "unknown". Removals of adults (pre-spawn) occur annually from some streams and estimates of these were provided by SEP. Removals include those removed for the purpose of: brood stock, given to First Nations, surplus to spawning requirements (ESSR), sold, mortalities (from holding) and "other".

---

[2] Parken, C., Ritchie, L., Macdonald, B., Bailey, R., Nicklin, P., Bradford, M., Ward, H., Welch, P., Boyce, I., Tompkins, A., Maxwell, M., Beach, K., Irvine, J., Grant, S., Van Will, P., Willis, D., Staley, M., Walsh, M., Sawada, J., Scroggie, J., and McGrath, E. Wild Salmon Policy Biolgoical Status Assessment for Conservation Units of Interior Fraser River Coho Salmon (*Oncorhynchus kisutch*). Canadian Science Advisory Secretariat (CSAS) Working Paper 2014/15SAL12.

All escapement estimates are available with significant meta-data, the most valuable of which (for our purposes) are the data quality rankings for each escapement estimate generated and the break out of escapement estimates to adults and jacks (and others), where possible. Data quality is ranked on a scale from Type-I (true abundance) through Type-VI (relative abundance), with escapements with a quality ranking of Type V or greater being considered to be highly uncertain. To ensure data quality was correctly represented in the nuSEDS database, DFO biologists reviewed all data in both EVI-GS and GSM CUs with the exception of streams in Area 13 (EVI-GS).

As escapement to the majority of streams is not assessed, we used an infilling approach to generate estimates of escapement to each CU as outlined in English et al. (2006). The primary assumption of this approach is that escapement to streams co-varies in a similar fashion year-to-year. The critical step in this approach is identifying streams with the most reliable escapement record, hereafter referred to as indicator streams. Following thorough review of the nuSEDS database, streams with escapement estimates of higher quality than Type IV in 50% of the years of interest (1990-2013) were identified as indicator streams (Table 4) (Brown et al., unpublished manuscript; Parken et al., unpublished manuscript)[3]. Following the identification of indicator streams, an infilling algorithm was run using estimates of Total Adult Return (nuSEDS estimates) plus removals. The infilling routine provided estimates of "Total Return" to each CU. To estimate the actual number of fish that spawned (Total Spawner Abundance), known removals from each CU were subtracted from the Total Return. Note that, since Area 13 escapement was unable to be reviewed, no Area 13 streams were considered for inclusion as indicator streams.

Spawner-recruit data was compiled from return year 1990 through 2013. While exploitation rate data is available for Black Creek back to 1986, we were unable to estimate hatchery contribution to escapement for return years 1986-1989 due to poor quality smolts released from Big Qualicum hatchery (discussed further in the next section).

3.1.3. Hatchery Contribution Data

To estimate the number of natural (wild) origin spawners in each CU, the number of hatchery origin salmon that survive to return to their natal rivers must first be estimated. Canada's Wild Salmon Policy is concerned with wild salmon, and therefore enhanced salmon must not be included in any analysis. Further, estimates of natural spawners are required to compare against WSP benchmark metrics once they are established.

Recent analysis of EVI-GS CWT releases and recoveries (marine) indicates differing migration routes, depending on the geographic location of the stream of origin. Specifically, CWT releases from Southern Vancouver Island tend to be recovered more in southern areas (Washington, Oregon, Juan de Fuca, and WCVI) than in northern areas (Central BC, Johnstone Strait) (Steve Baillie, DFO, Stock Assessment, South Coast Area, Nanaimo, BC, pers. comm.). While there does not appear to be a specific cut-off location that determines whether smolts travel north or south, there is a gradient whereby as release location moves north, an increasing number of releases migrate via a northerly route. This is important for our analyses since differential exploitation and survival will be experienced by fish from Goldstream than by fish from Big Qualicum or Quinsam. For this reason, when estimating enhanced origin return (see below) for all Coho Salmon released in statistical area 17 and south we used Goldstream exploitation and survival data. Similarly, exploitation rate and survival of all releases north of statistical area 17 were calculated using the average of Big Qualicum and Quinsam River exploitation and survival rates.

---

[3] Brown, G.S., Baillie, S,J., Bailey, R.E., Candy, J.R., Holt, C.A., Parken, C.K., Pestal, G.P., Thiess, M.E., and Willis, D.M. . Pre-COSEWIC review of southern British Columbia Chinook salmon (*Oncorhynchus tshawytsca*) conservation units, Part II: Data, analysis and synthesis. Canadian Science Advisory Secretariat (CSAS) Working Paper 2013/14

We estimated the number of enhanced origin salmon that contributed to Total Return in a particular year through a simple, multi-step process. Using SEP release records we summed data for each release stage (fry, fed fry, smolt 1+ and seapen) in each CU by brood year to generate a total number of released fish at each stage and CU (Appendix 4). Using a method similar to Parken et al. (unpublished manuscript)[4], we applied estimates of marine survival and exploitation to each life stage to generate an estimate of the number of enhanced origin salmon that survived to escape ("Enhanced Return"). In many cases, particularly with released fry, direct estimates of survival and exploitation were not available (Table 5). Where this was the case, we assumed a 20% survival from fry to smolt and then used available smolt to adult survival and exploitation data for hatchery origin stocks (Table 6) to estimate enhanced return. For those years where survival and exploitation rates were available for enhanced origin fry we pooled data by brood year and estimated survival as the total catch plus escapement divided by the total released. Dividing Enhanced Return by Total Return provided an estimate of "Enhanced Contribution" which is the proportion of fish that returned each year that are of enhanced origin. Thus, the spawning escapement of enhanced origin fish was estimated by multiplying the Enhanced Contribution by Total Spawner Abundance. By extension, annual estimates of natural (wild) spawner abundance (S) were estimated by multiplying Total Spawner Abundance by the natural contribution (1 – Enhanced Contribution).

Enhanced contribution for brood years 1983-1986 were found to be larger than expected (i.e. greater than 1.0). A value greater than 1.0 indicates that more enhanced origin fish entered a river than enhanced and wild combined, and is not possible. For these brood years, DFO notes that smolts produced from the Big Qualicum hatchery were of poor quality and estimates of exploitation and survival for these fish are unreliable. By extension, so are the estimates of enhanced contribution for these years. We therefore use only estimates of enhanced contribution from brood years 1987-2010 (return years 1990-2013).

3.1.4. Wild Spawner and Recruit Data

Abundance of wild adult recruits (those available pre-fishery) was estimated by dividing the natural spawner abundance (S_t) in year t by 1 - ER_t. All fish are assumed to be 3 years old and therefore, recruitment is offset by +3 years such that recruits in 1993 were from the 1990 escapement.

3.1.5. Converting Adult Recruits to Smolt Recruits

Adult recruit values were converted to smolt recruits for each brood year by dividing the adult recruit values by the marine survival in the return year (Table 3). Benchmarks developed from the spawner-adult recruit fits make the assumption that the average marine survival over the period of record will hold in the future. Benchmarks based on the spawner-smolt recruit models can be based on any assumed future marine survival rate.

---

[4] Parken, C., Ritchie, L., Macdonald, B., Bailey, R., Nicklin, P., Bradford, M., Ward, H., Welch, P., Boyce, I., Tompkins, A., Maxwell, M., Beach, K., Irvine, J., Grant, S., Van Will, P., Willis, D., Staley, M., Walsh, M., Sawada, J., Scroggie, J., and McGrath, E. 2014. Wild Salmon Policy Biolgoical Status Assessment for Conservation Units of Interior Fraser River Coho Salmon (*Oncorhynchus kisutch*). Canadian Science Advisory Secretariat (CSAS) Working Paper 2014/15SAL12.

3.2. METHODS

3.2.1. Stock-Recruit Model Structure

We estimated parameters for Beverton-Holt (BH) and Logistic Hockey Stick (LHS) stock-recruitment models based on both spawner-adult recruit and spawner-smolt recruit data sets. The form of the BH model applied here is (Hilborn and Walters 1992):

Equation (4)

$$\hat{R}_{i,t} = \frac{\alpha_i E_{i,t-3}}{1 + \frac{\alpha_i}{\beta_i} E_{i,t-3}}$$

where, $\hat{R}_{i,t}$ is the predicted number of adult or smolt recruits from CU 'i' in year 't', $E_{i,t-3}$ is the observed escapement to CU 'i' in year t-3, α_i is the initial slope of the line and is equivalent to the number of recruits produced per spawner at low density (stock productivity), and β_i is the maximum number of recruits that can be produced from the CU (carrying capacity).

The form of the LHS model (Barrowman and Myers 2000) is:

Equation (5)

$$R_{i,t} = \alpha_i C\delta_i (1 + e^{\frac{-1}{C}}) \left[\frac{S_{i,t-2}}{C\delta_i} - \log\left(\frac{1 + e^{(S_{i,t-2} - \delta_i)/(C\delta_i)}}{1 + e^{\frac{-1}{C}}}\right) \right]$$

where,

Equation (6)

$$\delta_i = \frac{\beta_i}{\alpha_i} \left[C(1 + e^{\frac{-1}{C}}) \left(\frac{1}{C} + \log(1 + e^{\frac{-1}{C}}) \right) \right]^{-1}$$

As for the BH model, stock-recruitment parameters α_i and β_i are estimated. C is a tuning parameter that determines the smoothness at the transition between the initial slope at low stock size and the asymptote at higher stock size. The LHS model approaches the hockey stick model as $C \rightarrow 0$. In this analysis, the tuning parameter was held constant at $C=1$.

We did consider applying the Ricker model. In an earlier analysis of southern BC Coho Salmon spawner-adult recruit stock-recruitment data, information theoretic approaches were unable to distinguish between Ricker and BH models owing to the extensive scatter in the data. However, a comparison of Ricker, BH and LHS models based on 17 spawner-to-smolt datasets from the Pacific Northwest indicated that the latter two models had much more support than the Ricker model (Korman and Tompkins 2014). As this analysis makes the standard assumption that the majority of density dependence for anadromous salmonids occurs in freshwater, the model selection results from Korman and Tompkins (2014) also apply here, and we therefore did not evaluate the Ricker model further. However, we do use information theoretic approaches to compare BH and LHS model results for the data from the two southern BC Coho Salmon CUs analyzed here.

Stock-recruit parameters were estimated by assuming that residuals of log-transformed data were normally distributed. That is, error in recruitment predictions is assumed to be lognormally distributed. The likelihood of observing $R_{i,t}$ recruits given a set of parameter estimates is computed from,

$$L(R_{i,t} \mid \alpha_i, \beta_i, \sigma_i) = \frac{1}{\sqrt{2\pi\sigma_i^2}} e\left[-\frac{[\log(R_{i,t}) - \log(\hat{R}_{i,t})]^2}{2\sigma_i^2} \right]$$

Equation (7)

where, Ri,t is the observed number of recruits, $\hat{R}_{i,t}$ is the predicted number of recruits from Equation (4) or Equation (5), and σi is the estimated standard deviation of the residuals around the stock-recruitment relationship. σ_i represents the extent of process error as we assume there is no observation error in the data.

Benchmarks derived from stock-recruit parameters were:

(1) the harvest rate to produce Maximum Sustainable Yield (Umsy);

(2) escapement to produce MSY (Smsy); and

(3) the escapement required to recover to Smsy in one generation (Sgen).

Benchmarks were computed using both spawner-adult recruit and spawner-smolt recruit stock-recruitment parameters. Benchmarks based on spawner-smolt recruit relationships were computed assuming future marine survival rates of 1.0%, 2.5%, and 5%. These rates were selected as they accurately reflect the range of both current (1%-2.5%) and near-term future survival expectations. Benchmarks based on spawner-adult recruit relationships require no specification of future marine survival rates. However, as the mean of the prior distribution of maximum recruitment for the spawner-adult stock-recruitment estimation was based on the average of historical marine survival rates (see below), the benchmarks implicitly assume an equivalent marine survival rate in the future. All benchmarks were estimated by non-linear optimization using the L-BFGS-B algorithm for the *optim* function of the 'R' statistics package (R Core Team 2014).

3.2.2. Parameter Estimation

Stock-recruit parameters were estimated using a Bayesian approach where the posterior distributions of parameter estimates ($P(\alpha_i, \beta_i, \sigma_i)$) depend on the prior distributions ($p(\alpha_i, \beta_i, \sigma_i)$) and the likelihood of the data given parameter estimates ($L(R_{i,t} \mid \alpha_i, \beta_i, \sigma_i)$, Equation (7)):

$$P(\alpha_i, \beta_i, \sigma_i) \sim p(\alpha_i, \beta_i, \sigma_i) * L(R_{i,t} \middle| \alpha_i, \beta_i, \sigma_i)$$

Equation (8)

We used an uninformative uniform prior for stock productivity (α_i for both the BH and LHS models) with minimum and maximum bounds of 0.05 – amax, where amax= 200 when fitting spawner-smolt recruit relationships, and amax=200*0.07 (=14) when fitting spawner-adult recruit relationships. The upper limit of spawner-smolt recruit productivity (200) was based on the asymptotic maximum value from the hyper-distribution of stock productivity estimated by Korman and Tompkins (2014, Figure 4), and 0.07 was the near maximum marine survival for the wild Black Creek Coho Salmon indicator stock over the period of record (Figure 5). We used an uninformative uniform prior for process error (σ_i) specified in terms of precision (τ_i), with minimum and maximum bounds of 0.01 and 10, respectively (note that $\sigma_i = \frac{1}{\sqrt{\tau_i}}$). We used a range of lognormal priors for maximum recruitment (β_i) with a mean determined as the product of the maximum number of smolts produced from each CU as determined by accessible stream length (computed from the Habitat Capacity Model, see Section 4.2.2) and the historical average marine survival (0.027, determined based on log-transformed marine survival from Black Creek) when fitting spawner-adult recruit relationships, and simply the maximum number of smolts when fitting spawner-smolt recruit relationships. The standard deviation of the prior distribution for maximum recruitment (coefficient of variation, prCV) was set to informative (prCV=0.1), moderately informative (prCV=0.3), and uninformative (prCV=0.6) levels (note: for lognormal distributions, the CV is approximately equal to the standard deviation).

Posterior distributions of stock-recruit parameters were estimated using Markov chain Monte Carlo (MCMC) sampling in WinBUGS (Spiegelhalter et al. 1999) version 1.4 called from the 'R' statistical package (R Development Core Team 2014) via the R2WinBUGS library (Sturtz et al. 2005). Three chains with different initial values for stock productivity and maximum recruitment were simulated. A total of 6,000 iterations were completed for each chain with the first 1,000 discarded to remove potential effects of the random parameter values used to initiate the simulations. Posterior distributions were based on saving every 5th sample from the remaining 5,000 iterations for a total sample size of 1,000 for each chain. This sampling approach was sufficient to achieve model convergence in all cases, which was evaluated using the Gelman-Rubin convergence statistic (Gelman et. al. 2004). Benchmarks were computed for each posterior value, and results were summarized based on the means and the 95% credible intervals generated. The deviance information criterion (DIC, a Bayesian version of Aikake Information Criteria) was used to compare BH and LHS models for each set of information (Spiegelhalter et al. 2002). As information in Bayesian analysis includes the actual data as well as the priors, models were compared for each unique combination of CU (EVI-GS, GSM) and prior distribution for maximum recruitment (3 prCVs). The analysis was conducted for both spawner-adult recruit and spawner-smolt recruit relationships.

4. RESULTS

4.1. HABITAT MODEL

Coho Salmon habitat, as determined by the model, is widely distributed among all streams as shown in Figure 1. From a CU perspective, we found that the EVI-GS CU had the most amount of habitat available (1,765 km), and was also the most productive, capable of producing 1.5 million smolts and 42,000 spawners. From a MU perspective, the LFR MU had the most habitat available (2,572 km); and was the most productive, producing 3.0 million smolts and almost 80,000 spawners. Table 7 provides estimates of total accessible habitat, total number of smolts produced, and the number of adult spawners required to produce said number of smolts for each CU and MU. The total numbers of smolts and spawners for each MU are simple sums of their component CUs, while the upper and lower CIs cannot simply be summed, and are thus calculated separately. Despite their wide geographic distribution, and the large number of streams accessible to Coho Salmon in each CU, we found that production of Coho Salmon is generally dominated by the four most productive streams for each CU. Accessible stream length of each of these four streams, the number of smolts and spawners produced from them as estimated via the Habitat Model are provided in Table 8. One hundred percent of production in Boundary Bay originates from the four most productive rivers (as there are only four), while the Lower Fraser CU has the most diverse production as only 42% of total spawners are produced by the four most productive streams. Estimated accessible lengths for all streams at gradients between 2% and 8% are provided in APPENDIX 2: COHO SALMON-BEARING SALMON STREAMS

Table A2. Smolt production and the required number of spawners to seed available habitat for each stream, as estimated by the model, are available in APPENDIX 3: STREAM-SPECIFIC ESTIMATES OF SMOLTS/SPAWNERS

Table A3.

The results suggest that appropriate escapement goals should be in the range of 42,000 spawners for EVI-GS, 10,000 for the GSM, 20,000 for HS-BI, 39,000 for LFR, 16,000 for BB and 24,000 for LILL.

4.2. STOCK-RECRUIT ANALYSIS

4.2.1. Wild Spawner and Recruit Estimates

Wild spawners, recruits and data used for infilling for each return year in the EVI-GS and GSM CUs are provided in Table 9. Adjustment Factors 1 and 2 indicate the factor by which escapement estimates are adjusted. "Adj Factor 1" adjusts observed escapement to indicator streams to account for indicator streams that were not assessed in a given year. "Adj Factor 2" adjusts the escapement to indicator streams to account for all other streams in the CU that were not assessed directly. Adjustment factors vary due to the different streams that are assessed on an annual basis. Adjustment factors will also change over time as new escapement data become available and the relative contribution that each stream contributes to monitored escapement is updated. Larger adjustment factors indicate that fewer streams were monitored in that year; a factor equal to 1 indicates that all streams were monitored in that year. Removals vary significantly from year to year for both CUs, and is very much higher in the EVI-GS CU, where it ranges from 2,627 to 34,827, the majority of which is composed of ESSR removals at Big Qualicum (26,803 in 1993, for example).

Total enhanced origin escapements are similarly much higher for the EVI-GS CU, which has some enhancement facilities capable of producing very large numbers of enhanced fish. The enhanced contribution to escapement is highly variable for both EVI-GS and GSM CUs, but particularly significant for EVI-GS where it was as high as 0.82 in 1992, and never below 0.24 (Table 9).

4.2.2. Stock-Recruit Results

Using the product of the historical average of Coho Salmon marine survival rate of 0.027 and average smolt production determined from accessible stream length for each CU (EVI-GS=1,603,226; GSM=395,603), the means of the lognormal prior on maximum adult recruitment when fitting spawner-adult recruit relationships were log(49,422) and log(11,968), respectively. The log of the smolt production values (e.g., log(1,603,226) for EVI-GS) was used as the mean when fitting spawner-smolt recruit relationships.

There was considerable scatter in stock-recruitment relationships (Figure 6). Three patterns were apparent:

(1) considerable variation in recruitment at low stock size;

(2) no obvious carrying capacity limit; and

(3) higher recruitment and spawning stock size in the first half of the period of record when marine survival rates were higher.

These patterns make it difficult to reliably estimate stock-recruit parameters. In an earlier analysis of these data, we fitted separate stock-recruitment models to data before and after 1990 when there was a rapid decline in marine survival (Figure 5). Unfortunately, this analysis produced nonsensical results (higher productivity estimates during the low marine survival period) because there was insufficient contrasts in spawning stock size when the data was essentially split in two. This was the motivation to reconstruct the smolt-recruit time series by dividing adult recruitment by the brood year marine survival rate.

For the most part, differences in stock productivity and carrying capacity estimates between the BH and LHS models were relatively minor. For the BH model applied to EVI-GS, the mean of the prior on carrying capacity based on stream length was very similar to what the spawner-adult recruit and spawner-smolt recruit data implied (Figure 7, see CV=0.6 results where effects of prior are minimal). As a result, the priors on carrying capacity had only a minor effect on the shape of the mean stock-recruitment curves that were estimated. However, increased certainty in the prior for carrying capacity (lower CVs) led to greater certainty in the stock-recruitment relationship. For the LHS model applied to EVI-GS, habitat-based carrying capacity was less than what the stock-recruit data implied, especially based on spawner-smolt data (Figure 8). As a result, increasing the certainty in the prior on capacity led to a reduction in the carrying capacity estimated by the stock-recruit model. For the GSM CU, stream length-based estimates of carrying capacity were greater than what the stock-recruit data implied for both BH and LHS models (Figure 9, Figure 10, respectively). As a result, increased certainty in the prior led to higher estimates of carrying capacity in the stock-recruit analysis.

Estimates of stock productivity and carrying capacity from the LHS spawner-smolt recruit models for the EVI-GS CU were consistent with the regional distributions estimated by Korman and Tompkins (2014,Figure 4, Figure 11). Estimates of carrying capacity from the BH model were also consistent with the regional distribution, but the CU-specific estimates of stock productivity from this model were much higher than those from the regional distribution. This likely indicates that the uncertain stock-recruit data used in this analysis is leading to an overestimate of stock productivity based on the BH model. For the GSM CU, both stock-recruit models tended to underestimate carrying capacity relative to regional distributions, and overestimate stock productivity. The difference in stock productivity was especially acute for the BH model. As for the EVI-GS result, we suspect these differences are due to uncertainties in the stock-recruit data used in this analysis.

The DIC analysis showed support for the BH model over the LHS model for both adult and smolt recruit datasets under all prior scenarios for EVI-GS (Table 11). Differences in DIC between BH and LHS models were more modest for GSM, but there was stronger support for the BH model in the majority of cases.

Table 10 summarizes the benchmark statistics for each CU based on BH and LHS models for adult-recruit and smolt-recruit analyses. In this discussion of benchmarks that follows, we focus on trends in Umsy, arguably the most practical benchmark given that:

(1) estimates of escapement and recruitment are highly uncertain, thus benchmarks that depend on evaluating status based on abundance are impractical;

(2) recruitment forecasts are highly uncertain, so it is impractical to manage harvest towards a fixed escapement goal (e.g., Smsy or Sgen); and

(3) Umsy can be implemented more effectively since time and area closures can be managed to attain a target harvest rate regardless of stock size.

Zero values for Smsy and Umsy are due to the initial slope of the recruitment curve (productivity) being lower than the replacement line at 1% marine survival (red dashed lines in Figure 7 - Figure 9). The DIC analysis indicates that more emphasis should be placed on results from the BH model, however stock productivity estimates from this model were considerably higher than those from the regional analysis, suggesting that they are likely too high. Given only modest support for the BH model in the DIC analysis, we instead emphasize results from the LHS model.

Umsy for EVI-GS based on BH and LHS models and the adult recruit analysis were 0.67 and approximately 0.36 for BH and LHS models, respectively (Table 10). Umsy was much higher for the BH model owing to its greater flexibility in shape, leading to higher stock productivity estimates given the pattern in stock-recruit data (Figure 7, Figure 8). The 95% credible interval in Umsy was quite wide reflecting uncertainty in stock productivity estimates, and there was a small amount of overlap in intervals between BH and LHS models. For smolt-recruit based estimates, Umsy increased with the assumed base marine survival rate. Assuming future values are close to 0.025 (most recent estimates) suggests Umsy ranges between 0.5 and 0.3 for BH and LHS models for this CU. We consider the latter estimate to be more realistic.

Umsy for GSM based on BH and LHS models and the adult recruit analysis were about 0.6 and 0.45, respectively (Table 10). As with EVI-GS results, Umsy was higher for the BH model owing to its greater flexibility in shape, leading to higher stock productivity estimates given the pattern in stock-recruit data (Figure 9 and Figure 10). The 95% credible interval in Umsy was quite wide reflecting uncertainty in stock productivity estimates, and there was considerable overlap in intervals between BH and LHS models. For smolt-recruit based estimates, Umsy increased with the assumed base marine survival rate. Assuming future values are close to 0.025 (most recent estimates) suggests Umsy ranges from about 0.4 to 0.5.

5. SENSITIVITY ANALYSES

5.1. ACCESSIBLE STREAM LENGTH DETERMINATIONS

The determination of accessible Coho Salmon habitat is the first point where error can be introduced to the Habitat Model. In the model, we used known barriers (where available) as the upper limit of Coho Salmon accessibility in each watershed. However, for many systems, barriers may not be identified, or the upper limit is determined by stream gradient. We used a stream gradient of 100% (45°) for greater than 10 m (i.e., a rise of 10 m over 10 m) as a gradient barrier to Coho Salmon.

To test model sensitivity to the 8% gradient used as the upper limit of Coho Salmon distribution (pre-smolt rearing habitat) and the stream order algorithm used, the model was run using upper gradient limits ranging from <2% to <8%. The model was also run using minimum stream orders ranging from 1 to 4 to estimate smolt production under each scenario. Recall that as minimum stream order increases, the amount of habitat available decreases, and as such, less habitat will be available when using a minimum stream order of 3 than 1. Decreasing the upper gradient limit for accessibility similarly decreased the estimate of accessible stream length.

The amount of accessible habitat estimated by the model was robust to gradient, but highly variable under different assumptions of minimum stream order. When tested across gradients of 2% to 8%, habitat availability was found to decrease by a maximum of 17% (HS-BI) from the base case of 8% gradient to 2% gradient (Table 12). However, as the minimum stream order to include increased from 1 to 4 (resulting in less habitat), the percent of available habitat decreased between 88% (BB) and 53% (LILL) (Table 12). The model was similarly sensitive to the number of spawners required to fully seed habitat when gradient and minimum stream order were both allowed to vary (Table 13).

5.2. SMOLTS PER SPAWNER

The model was tested for sensitivity to the assumed amount of smolts produced per spawner. We assumed that each spawner in each CU produced 38 smolts per spawner, therefore each CU is equally sensitive to this parameter. We tested the sensitivity of the model for a range from 20 – 100 smolts per spawner. At an assumed 20 smolts per spawner, the number of spawners would have to be increased by 90% from the base case, while at an assumed 100 smolts per spawner, a reduction of 62% from the base case would need to occur to produce the average number of smolts (Table 14). The required number of spawners has an inverse relationship to the number of smolts produced per spawner such that as the number of smolts per spawner decreases, the number of spawners required to produce the average number of smolts increases.

6. DISCUSSION

Identification of escapement goals is critical for management of South Coast Coho Salmon stocks. The Coho Salmon Habitat and Stock-Recruit models described here attempt to quantify escapement needs for Coho Salmon in this area based on our assumptions and the available data, previously described. We specifically abstain from recommending Wild Salmon Policy benchmarks, particularly those based on stream-specific escapement goals as this is better left to others when setting stock management and fishery management objectives.

Habitat capacity model estimates of required spawners do not account for marine survival whereas the stock and smolt-recruit models do. Consequently, the benchmarks Sgen and Smsy are not directly comparable to the number of spawners identified by the Habitat Model.

6.1. HABITAT CAPACITY MODEL

The hypothesis of correlation between smolt yield and stream length is well supported in the literature and the use of the large, local smolt data set coupled with sensible and literature-supported estimates of smolts produced per spawner ensures robustness across differing stream sizes and types.

6.1.1. Stream Length

Digital Terrain Resource Information Management (TRIM) maps at a 1:20,000 scale for Statistical Area 3 were used for this model. TRIM maps are derived from air photo interpretation and are considered to be accurate to within 10 m, 90% of the time (Brown et al. 1996). However, tree vegetation makes capture of all waterways difficult from air photos. In an examination of TRIM mapping with ground surveys, Brown et al. (1996) found that TRIM delineated 80% of the natural channel length in basins with terrain relief. The percentage delineated by TRIM in areas of low relief was 73%. The watersheds included in the model have significant terrain relief, particularly those from the HS-BI GSM, and LILL CUs, and TRIM likely captures the majority of the stream network that is accessible to Coho Salmon.

6.1.2. Effect of Map Scale

Model estimates of available habitat were derived using regional data of smolt production for which stream length was derived from the GIS work that accompanied this analysis. Paired estimates of available anadromous habitat (DFO), or mainstem length (BC Hydro and Metro Vancouver) accompanied all but one stream (i.e., Millstone River) estimate of smolt production (Table *15*) (Steve Baillie, DFO, South Coast, Stock Assessment, Nanaimo BC, pers.comm; BC Hydro 2011; 2012a; 2012b; Metro Vancouver 2012). In some cases (i.e., Salmon River), it was unclear if reported length included upstream tributaries (Coghlan Creek). Length of available habitat as calculated via GIS is expected to be larger than that provided from other sources as the GIS estimate includes all accessible habitat (i.e., in tributaries, ditches, side channels, etc.) downstream of modelled barriers. The methods used to calculate accessible habitat by DFO are based on 40 year-old Stream Catalogues, were not necessarily explicitly measured, and likely exclude small tributaries and ditches. Furthermore, the GIS analysis is comprehensive and descriptive in its assessment of accessibility as it accounts for stream gradient and all known barriers of the mainstem and tributaries. In all cases, the GIS estimate of accessible habitat was used for the predictive regression and in the Habitat Model.

6.1.3. Limits to Smolt Production

Coho Salmon smolt production appears to be independent of the number of spawners except at low spawner abundances (Bradford et al. 2000, Knight 1980, Holtby and Scrivener 1989). Nickelson et al. (1992) concluded that Coho Salmon in Oregon are likely limited by the availability of winter habitat (also Brown and Hartman 1988). Furthermore, several authors have documented the seasonal movement of Coho Salmon juveniles from upper watershed areas to lower watershed areas in the fall and vice-versa in the summer (Brown et al. 1999, Cederholm and Scarlett 1991). Downstream movement is likely in preparation for smolting and perhaps a response to habitat contraction due to drying or freezing while movement upstream in the summer is in response to habitat contraction, when juveniles find refuge in swamps, ponds and pools. It is these behaviours which likely enable the prediction of smolt production from available rearing habitat (e.g., stream length) in the higher order streams within a watershed.

Freezing in winter, and low flows in the summer reduces available habitat in some of the watersheds in the Habitat Model, particularly for the GSM, HS-BI, and LILL CUs. The life stages of salmonids at the critical times of fall fry and pre-smolts become the limiting stages to total smolt production. During these times, habitat available to rearing salmonids may be contracted and the mainstem and primary tributaries, lakes and swamps account for a greater proportion of the available and useable habitat. It is this interrelation between critical flow and available habitat that further allows for stream length to be a reasonable predictor of smolt production.

Bradford et al. (1997) show that smolt abundance was best explained by stream length and latitude and is the premise upon which the work herein is based. However, this explanation does not take into account watershed geomorphology, or other factors, which have also been shown to have a significant effect on smolt production. Sharma and Hilborn (2001) show that smolt abundance declines with increasing gradient and valley slope. Following this logic, CUs with a greater proportion of high gradient habitat (or valley slope) would be less productive than CUs with a greater proportion of low gradient habitat. The potential for bias due to different productivities of rivers with different geomorphologies in our assessment exists, but only if CUs have different amounts of high gradient habitat. From our analysis, it is clear that some CUs (HS-BI and GSM) have more high gradient habitat than others (BB) (Table 12). However, when comparing gradients of 8% to 2% under access to streams of order 1 or greater, there is only a difference of 4% in the amount of high gradient habitat in BB than either GSM or HS-BI (Table 12). Therefore, any bias due to watershed geomorphology differences would likely be very small.

6.1.4. Required Number of Spawners

The applicability of the predictive regression to estimate the number of spawners required to produce the average number of smolts carries with it many assumptions. Perhaps foremost, the model assumes that the empirical smolt data (Table **A1**) reflects the average productive capacity of the region. That is, annual smolt estimates are from a range of high and low spawner abundances where habitat would be both fully and under seeded by spawners. Black Creek is the only stream in our CUs with paired spawner smolt data of sufficient quality and length of time series to assess this assumption (Figure 12). It is evident that smolt production data is available for years when habitat was poorly seeded (data points left of the asymptote) and fully seeded (data points to the right) with adult spawners. This indicates that, at least for Black Creek, smolt production reflects the average (note that Figure 12 differs from Figure 11 where data is over a different time period and with a different estimate of accessible stream length).

The Habitat Model further assumes that the historical smolt data used to derive the model is reflective of current and future smolt productive capacity for the geographic region included. Although this is consistent with the thinking of previous researchers; namely that average smolt production is an appropriate measure of capacity (Marshall and Britton 1990, Bradford et al. 1997, Burns 1971); this assumption should be tested in future research.

The Habitat Model presented in this paper predicts the number of spawners required to produce the average number of smolts based on available habitat. It ignores potential production from ocean-type Coho Salmon that leave the freshwater environment in their first year. For systems where ocean-type Coho Salmon contribute to total Coho Salmon production measured by adult returns, the models would underestimate the required number of spawners to maximize total production. The Quinsam River hatchery monitors annual out-migration of wild fry, and in some years, fry migration is significant (325,000 in 1989). While research on Coho Salmon fry emigration and their consequent contribution as spawners is sparse, Lindsay (1974) found that only 0.1% of fry emigrants from small Coastal Oregon streams returned as adults, meaning that even when fry emigrations are large, their contribution to adult spawners is likely minimal. Similarly, to the extent that Coho Salmon from adjacent streams rear in non-natal streams in the study area, there will be errors in the predicted number of required spawners for those systems. However, no data is available to assess this potential bias.

It should be noted that our model presents the number of successful spawners required to produce the average number of smolts. Should pre-spawn mortality be significant enough, as it has for some urban streams in the Puget Sound region (Scholz et al. 2011), management would need to increase escapement proportionally to account for estimated mortality such that the number of successful spawners is equal to that presented here.

We caution that this model is not designed for use on a stream-specific basis due to the potential for considerable error in the predictions for some streams, but rather on an multi-stream basis, these predictions are a step toward improving fishery management capability for these Coho Salmon management units, especially where escapement goals for Coho Salmon do not currently exist.

6.1.5. Sensitivity Analysis

The average number of smolts, and therefore spawners, required is sensitive to the linear distance of available stream habitat. Table 12 provides estimates of available habitat in each CU for each combination of stream order and gradient. Should assumptions behind the accessibility of habitat change, the required number of smolts (and spawners) would also change. Table 13 provides the percent change in required number of spawners from the base case should assumptions behind accessibility change. For these CUs, available habitat was not particularly sensitive to gradient, particularly in the Boundary Bay CU which is located in the flood plain of the Fraser River and has significant agricultural activity (i.e. low variation in gradient). For similar reasons, availability of habitat in Boundary Bay is highly sensitive to the order of stream included. Should the upper stream orders (1, 2, 3) be unavailable to Coho Salmon, habitat would be greatly reduced in this CU. On the other hand, CUs with mountainous geography (LILL and GSM) were the most sensitive to assumptions of gradient. In all CUs, amount of accessible habitat was found to be particularly sensitive to the minimum stream order to include.

We assumed that the number of smolts produced per spawner were, on average, consistent across each stream and CU. In reality, there is a high degree of variability in the actual number produced per spawner per stream (Table 2). This variability is further reflected in published estimates of smolts per spawner, which can average 65 (range of 25 -125) (Sharma and Hilborn 2001; Sharma et al. 2005), or be as low as 43 at low spawner abundances (Bradford et al.

2000) or as high as 104 at high spawner abundances (Korman and Tompkins, 2014; Figure 4). Despite the literature supporting a wide range of estimates of smolts per spawner, we thoroughly evaluated data for the Quinsam River, and were able to verify that all smolts were in fact wild despite the Quinsam River having extensive enhancement activities on it. Further, all estimates of spawners that produced said smolts were of a data quality of Type-IV or better, which is the same standard of acceptable quality used to identify indicator streams. Considering we were unable to find any reason to doubt any of the smolt per spawner data in this, or other estimates, all available data was included. Our empirical estimate of 38 smolts produced per spawner is assumed to be the average.

Despite having smolt per spawner estimates specific to both the GSM (Myrtle Creek; 58 smolts/spawner) and LFR (Salmon River; 25 smolts/spawner) CUs, we chose to use the overall area average (38 smolts/spawner) when back-calculating the number of spawners. Our assumption here is that the area average better represents the GSM and LFR CUs than one individual stream per CU. Further, we tested the uncertainty in the number of smolts per spawner (Table 14) and found that the number of spawners would need to increase by 52% if 25 smolts per spawner were assumed, or reduced by 62% if 100 smolts per spawner were assumed. Further adjustments could similarly be made as needed in the future, on a case-by-case basis.

6.1.6. Comparison of Estimated Spawners from Habitat Model vs. Infill Routine

The required number of spawners as estimated via the Habitat Model were compared to the historical average number of spawners as estimated from nuSEDS data and the infill routine (1990-2013). We found that, on average, 20% and 50% fewer fish (EVI-GS and GSM, respectively) were allowed to escape than that required to produce average smolt abundances (Table 16).

6.2. STOCK-RECRUIT ANALYSIS AND BENCHMARKS

Our estimates of spawner-to-smolt stock productivity, defined as the slope at the origin of the spawner to smolt relationship, were somewhat higher than those determined from a recent regional analysis (Korman and Tompkins, 2014) for EVI-GS and GSM CUs, based on the Logistic Hockey Stick model (Figure 4). Umsy, an important and potential WSP benchmark is completely determined by this productivity. However, our results based on the Beverton-Holt model indicated considerably higher productivity, and hence Umsy, compared to the regional analysis as evidenced by the dark bars lying generally to the right of the curved lines in Figure 4. Despite there being generally a bit more statistical support for the BH model in this analysis, the discrepancy with the regional model results and the uncertain stock-recruit data used here leads us to recommend using estimates from the LHS model. This model predicts that at an assumed future marine survival rate of 2.5%, harvest rates of approximately 35-40% will produce MSY for EVI-GS and GSM CUs. Our estimate is higher than the 20% Umsy (at 2.5% survival, BH) estimated by Korman and Tompkins (2014) due to the higher estimates of stock productivity. Results presented here suggest that EVI-GS and GSM stocks are more productive and can support greater harvest rates. However, there was considerable uncertainty in our estimated rates owing to uncertainty in estimates of stock productivity, which were ultimately driven by the large scatter in stock-recruit points (Figure 6, Figure 7). Korman and Tompkins (2014) used a relatively high quality spawner-smolt stock-recruit data set from 16 coastal streams to estimate Umsy for Coho Salmon in Southern BC. We have much more confidence in estimates of stock productivity and Umsy from the regional analysis because the stock-recruit data used here are highly uncertain. The higher estimates of productivity we estimated here may be caused by errors-in-variables bias resulting from poorly determined spawning escapements. Harvest rates experienced over the last decade under a Coho Salmon fisheries closure (due to bycatch concerns) are approximately equal to the lower 95% credible interval limit of Umsy estimated here, or closer to the average estimated at 1% marine survival (1-4% for EVI-GS and GSM, respectively; Table 10).

Smsy for GSM Coho Salmon is consistent at marine survivals of 1% and 2.5% (3,000 and 3,100, respectively) whereas that of EVI-GS is much less consistent (1,500 and 24,800, respectively). A similar pattern is observed for Sgen with both GSM (1,200 and 1,600) and EVI-GS (1,800 and 13,900) at 1% and 2.5% survival, respectively. These are due to the increased productivity of EVI-GS relative to that of the GSM CU (Figure 8 and Figure 10). Considering the poor data from which these estimates are modeled and increased difficulty of managing fisheries to achieve an escapement objective (versus managing to a specified exploitation rate), we do not recommend these benchmarks for use by management.

7. CONCLUSIONS AND RECOMMENDATIONS

Average estimated smolt production and the number of spawners required to produce the average number of smolts for each CU were calculated respectively as 1,603,226 and 49,422 (EVI-GS); 395,603 and 11,968 (GSM); 751,868 and 22,784 (HS-BI); 1,484,479 and 46,005 (LFR); 910,977 and 27,605 (LILL); and 608,082 and 18,427 (BB) (Table 7). Estimated average smolt production and spawners for each MU were calculated respectively as 1,147,471 and 34,752 (GSM); 3,003,538 and 92,037 (LFR); and 1,603,226 and 49,422 (GS-VI). Results of the Habitat Model are dependent on the amount of habitat available, particularly as it applies to stream order, and to the number of smolts produced per spawner. We recommend the results of this model be reviewed by regional biologists and managers to assist with selection of indicator streams.

The results of the Logistic Hockey Stick model are preferred over those of the Beverton-Holt model, as the LHS results are more consistent with other work (Korman and Tompkins, 2014). The LHS stock-recruit model estimates that at an assumed future marine survival rate of 2.5%, harvest rates of approximately 35-40% will produce MSY for both EVI-GS and GSM CUs (Table 17). Smsy and Sgen were modeled, but are not recommended due to poor data quality (inputs) and the challenge of implementation. The results of the stock-recruit analysis are highly dependent on marine survival estimates.

Data deficiencies prevented stock-recruit analyses to be completed on all other CUs, which resulted in no stock-recruit analysis conducted on the GSM and LFR MUs. Therefore, a complete assessment of Coho Salmon at the MU level was not possible, and we recommend that a thorough review of nuSEDS data for Area 13 and the LFR, HS-BI and LILL CUs occurs to evaluate whether stock-recruit analyses are possible for these CUs and their component MUs. Upon conclusion of this review, specific streams should be identified for annual escapement work to ensure there is at least one indicator in each CU.

8. ACKNOWLEDGMENTS

We would like to acknowledge the contribution of several people to the development of this model. Robin Tamasi, Lucia Ferreira, Tony Mochizuki, and Megan Matthews of LGL participated in the development of the GIS components of the model to calculate accessibility from TRIM data. The support for this project by the Pacific Salmon Commission is greatly appreciated. Special thanks to Joel Sawada of DFO for his interest and support in this project. We also thank Steve Baillie (DFO), Pieter Van Wiel (DFO), David O'Brien (DFO), Arlene Tompkins (DFO), Bruce Baxter (DFO), Tracy Cone (DFO), Cheryl Lynch (DFO), Joan Bateman (DFO), Mary Thiess (DFO), Chuck Parken (DFO), Don McCubbin (InStream) and Jason Ladell (InStream) for providing advice on methods, providing the numerous datasets required, and BC16s. Thanks also to Jack Cooley (Squamish Steamkeepers), Ian Bruce (Peninsula Streams), Kevin Timothy (Tla'amin Fisheries), Grant McBain (DFO Community advisor, Sechelt), Sid Quinn (Sechelt Fisheries), Natashia Cox (Fraser Valley Watershed Coalition), Nanoose Creek hatchery staff, Capilano Hatchery staff, and Seymour River Hatchery staff; all of whom provided local knowledge regarding the status of barriers to Coho Salmon migration. We would also like to thank Mara Zimmerman (Department of Fish and Wildlife, Washington) and Carrie Cook-Tabor (US Fish and Wildlife) for their comments on a previous iteration of this report.

9. LITERATURE CITED

Adkison, M.D. and M.R. Peterman, 1996. Results of Bayesian methods depend on deaths of implementation: an example of estimating salmon escapement goals. Fish. Res. 25: 155-170.

Baranski, C. 1989. Coho smolt production in ten Puget Sound streams. Wash. Dep. Fish. Tech. Rep. 99: 29 p.

Barrowman, N.J. and R.A. Myers. 2000. Still more spawner-recruitment curves: the hockey stick and its generalizations. Can. J. Fish. Aquat. Sci. 57: 665-676.

BC Hydro. 2012a. Cheakamus Project Water Use Plan. Reference: CMSMON-1A.

BC Hydro, 2012b. Alouette Project Water Use Plan. Reference: ALUMON-1.

BC Hydro, 2011. Coquitlam-Buntzen Water Use Plan. Reference: COQMON#7.

BC Ministry of Environment. 2014. Fisheries Information Summary System (FISS) [online]. (Accessed July 1, 2014)

Bilby, R.E. and P.A. Bisson. 1987. Emigration and production of hatchery Coho Salmon (*Oncorhynchus kisutch*) stocked in streams draining an old-growth and a clear-cut watershed. Can. J. Fish. Aquat. Sci. 44: 1397-1407.

Bisson, P.A., R.A. Nielsen, R.A. Palmason, and L.E. Gore. 1982. A system of naming habitat types in small streams with examples of habitat utilization by salmonids during low stream flow. In Acquisition and utilization of aquatic habitat information. Edited by N.A. Armatrout. American Fisheries Society, Bethesda, MD. p. 62-73.

Blackett, R.F. 1979. Establishment of sockeye and chinook salmon runs at Frazer Lake, Kodiak Island, AK. J. Fish. Res. Board. Can. 36:1265-1277.

Bjorn, T.C. and D.W. Reiser. 1991. Habitat requirements of salmonids in streams. American Fisheries Society Special Publication 19: 83-138.

Bocking, B. and D. Peacock. 2004. Habitat-based production goals for coho salmon in Fisheries and Oceans Statistical Area 3. DFO. Can. Sci. Advis. Sec. Res. Doc. 2004/129. vii +77 p. (Accessed July 12, 2015)

Bradford, M.J., G.C. Taylor and J.A. Allan. 1997. Empirical review of Coho Salmon smolt abundance and the prediction of smolt production at the regional level. Trans. Am. Fish. Soc. 126: 49-64.

Bradford, M.J., R.A. Myers and J.R. Irvine. 2000. Reference points for Coho Salmon (*Oncorhynchus kisutch*) harvest rates and escapement goals based on freshwater production. Can. J. Fish. Aquat. Sci. 57: 677-686.

Brown, T.G. and G.F. Hartman. 1988. Contribution of seasonally flooded lands and minor tributaries to Coho (*Oncorhynchus kisutch*) salmon smolt production in Carnation Creek, a small coastal stream in British Columbia. Trans. Am. Fish. Soc. 1217: 546-551.

Brown, T.G., L. Barton, and G. Langford. 1996. The use of a geographic information system to evaluate terrain resource information management (TRIM) maps and to measure land use patterns for Black Creek, Vancouver Island. Can. Manuscr. Rep. Fish. Aquat. Sci. 2395: 34 p.

Brown, T.G., L. Barton, and G. Langford. 1999. Coho Salmon habitat within Black Creek, Vancouver Island. Can. Tech. Rep. Fish. Aquat. Sci. 2294: 75 p.

Burns, J.W. 1971. The carrying capacity for juvenile salmonids in some northern California streams. Calif. Fish and Game. 57(1): 44-57.

Cederholm, C.J. and L.M. Reid. 1987. Impacts of forest management on Coho Salmon (*Oncorhynchus kisutch*) populations of the Clearwater River, Washington: project summary, p. 373-398. In E.W. Salo and T.W. Cundy (ed.). Streamside Management: forestry and fisheries interactions. Contribution 57, College of Forest Resources, University of Washington, Seattle, WA.

Cederholm, C.J. and W.J. Scarlett. 1991. The beaded channel: a low-cost technique for enhancing winter habitat of Coho Salmon. Amer. Fish. Soc. Symposium 10: 104-108.

Chapman, D.W. 1965. Net production of juvenile Coho Salmon in three Oregon streams. Trans. Am. Fish. Soc. 94(1): 40-52.

DFO. 2005. Canada's Policy for Conservation of Wild Pacific Salmon. Fisheries and Oceans Canada, Vancouver, BC. 34 p .

DFO. 2011. Integrated Fisheries Management Plan Salmon Southern B.C. June 1, 2011 to May 31, 2012. Fisheries and Oceans Canada, 268 pp.

DFO. 2014. NuSEDS V2.0 Regional Adult Salmon Escapement Database. Southern BC Coho Salmon: 1990-2013. Retrieved November 1, 2013 (GSM, ECVI and HS-BI CUs), and May 6, 2014 (LILL, LFR and BB CUs).

Draper, N.R., and W. Smith. 1981. Applied Regression Analysis (Second Ed.). John Wiley and Sons. 709 p.

English, K.K., Peacock, D. and Spilsted, B. 2006. North and central coast core stock assessment program for salmon. Prepared by LGL Limited for the Pacific Salmon Foundation and Fisheries and Oceans Canada. 78 pp.

ESRI 2010. ARCINFO: Release 10.0. Redlands, CA: Environmental Systems Research Institute.

Faush, K.D., C.L. Hawkes, and M.G. Parsons. 1988. Models that predict standing crop of stream fish from habitat variables: 1950-85. USDA For. Serv. Gen. Tech. Rep. PNW-GTR-213, Portland, OR. 52 p.

Fransen, B. R., S. D. Duke, L. G. McWethy, J. K. Walter, and R. E. Bilby. 2006. A logistic regression model for predicting the upstream extent of fish occurrence based on geographic information systems data. N. Am. J. Fish. Man. 26: 960-975.

Geiger, H.J. and J.P. Koenings. 1991. Escapement goals for sockeye salmon with informative prior probabilities based on habitat considerations. Fish. Res. 11: 239-256.

Gelman, A., Carlin, J.B., Stern, H.S., and D.B. Rubin. 2004. Bayesian data analysis, 2nd Edition. Chapman & Hall/CRC, Boca Raton, FL. 668 p.

Hartman, G.F., B.C. Andersen, and J.C. Scrivener. 1981. Seaward movement of Coho Salmon (*Oncorhynchus kisutch*) fry in Carnation Creek, an unstable coastal stream in British Columbia. Can. J. Fish. Aquat. Sci. 39: 588-597.

Hilborn, R., and C.J. Walters. 1992. Quantitative fisheries stock assessment. Chapman and Hall, New York. 570 p.

Holtby, L.B. and J.C. Scrivener. 1989. Observed and simulated effects of climatic variability, clear-cut logging, and fishing on the numbers of chum salmon (*Oncorhyhnchus keta*) and Coho Salmon (*O. kisutch*) returning to Carnation Creek, British Columbia, p. 62-81. In C.D. Levings, L.B. Holtby, and M.A. Henderson [ed.] Proceedings of the National Workshop of Effects of Habitat Alteration on Salmonid Stocks. Can. Spec. Publ. Fish. Aquat. Sci. 105.

Holtby, L.B., B.C. Andersen, and R.K. Kadowaki. 1990. Importance of smolt size and early ocean growth to interannual variability in marine survival of Coho Salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 47: 2181-2194.

Horton, R. E. 1945. "Erosional Development of Streams and Their Drainage Basins: Hydrophysical Approach to Quantitative Morphology." Bull. Geol. Soc. Am. 56: 275-370.

Johnson, N.L., and S. Kotz. 1970. Distributions in Statistic: Continuous Univariate Distributions, Vol 1. John Wiley and Sons, New York. 300 p.

Jowett, I.G. 1992. River hydraulics and instream habitat modelling for river biota. In: Mosley, M.P. (Ed.), Waters of New Zealand, Wellington, New Zealand Hydrological Society, p 249-263.

Korman, J., and A. Tompkins. 2014. Estimating Regional Distributions of Freshwater Stock Productivity, Carrying Capacity, and Sustainable Harvest Rates for Coho Salmon Using a Hierarchical Bayesian Modelling Approach. DFO Can. Sci. Advis. Sec. Res. Doc. 2014/089 vii + 53 p. (Accessed July 12, 2015)

Knight, N.J. 1980. Factors affecting smolt yield of Coho Salmon (*Oncorhynchus kisutch*) in three Oregon streams. M.Sc. thesis, Oregon State University, Corvallis, OR.

Lindsay, R.B., 1974. Distribution and Survival of Coho Salmon Fry after Emigration from Natal Streams. A thesis submitted to Oregon State University.

Lister, D.B. 1968. Use of inaccessible stream areas for Coho Salmon production. Fish. Mar. Ser. MS Rep. On File No. 32-5-45: 9 p.

Marshall, D.E. and E.W. Britton. 1990. Carrying capacity of Coho Salmon streams. Can. Man. Rep. Fish Aquat. Sci. 2058: 32 p.

Mason, J.C. 1974. A further appraisal of the response to supplemental feeding of juvenile Coho (*O. kisutch*) in an experimental stream. Fish. Mar. Ser. Tech. Rep. 470: 25 p.

Mason, J.C. and D.W. Chapman. 1965. Significance of early emergence, environmental rearing capacity and behavioural ecology of juvenile Coho Salmon in stream channels. J. Fish. Res. Bd. Can. 22: 175-190.

Metro Vancouver, 2012. Seymour River Juvenile Salmonid Outmigration Monitoring, Spring 2012.

Minard, R.E., and Meacham, C.P., 1987. Sockeye salmon management in Bristol Bay, Alaska. In:H.D. Smith, L. Margolis, and C.C. Wook (Editors), Sockeye Salmon Population Biolody and Fugur Management. Can. Spec. Publ. Fish. Aquat. Sci. 96: 336-342.

MOE. 1977. Aquatic Biophysical Maps. Resources Analysis Branch. Ministry of the Environment. Victoria, B.C.

Nickelson, T.E. 1998. A habitat-based assessment of Coho Salmon production potential and spawner escapement needs for Oregon coastal streams. Information Reports Number 98-4. Oregon Department of Fish and Wildlife. Portland Oregon.

Nickelson, T.E., J.D. Rodgers, S.L. Johnson, and M. Solazzi. 1992. Seasonal changes in habitat use by juvenile Coho Salmon (*Oncorhynchus kisutch*) in Oregon coastal streams. Can. J. Fish. Aquat. Sci. 49: 783-789.

Pess, G.R., D.R. Montgomery, E.A. Steel, R.E. Bilby, B.E. Feist, and H.M. Greenberg. 2002. Landscape characteristics, land use, and Coho Salmon (*Oncorhynchus kisutch*) abundance, Snohomish River, Wash., U.S.A. Can. J. Fish. Aquat. Sci. 59: 613-623.

Powers, P.D. and J. F. Orsborn. 1985. Analysis of barriers to upstream fish migration: an investigation of the physical and biological conditions affecting fish passage success at culverts and waterfalls. U.S. Department of Energy, Bonneville Power Administration. Project 82-14 Final Report. Portland, OR.

Ptolemy, R.A., M. Ramsey, and D. Pollitt. 2004. Results of steelhead stock monitoring (1988-2004) in the Bella Coola River and implications for population recovery. Prepared for Ministry of Water, Land and Air Protection, Fish and Wildlife Science and Allocation, Victoria, BC.

R Core Team (2014). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. (Accessed July 12, 2015)

Reeves, G.H., F.H. Everest, and T.E. Nickelson. 1989. Identification of physical habitats limiting the production of Coho Salmon in western Oregon and Washington. U.S. Forest Service General Technical Report PNW-245.

Rosenfeld, J., M. Porter and E. Parkinson. 2000. Habitat factors affecting the abundance and distribution of juvenile cutthroat trout (*Oncorhynchus clarki*) and Coho Salmon (*Oncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 57: 766-774.

Scholz, N.L, Myers, M.S., McCarthy, S.G., Labenia, J.S., McIntyre, J.K., Ylitalo, G.M., Rhodes, L.D., Laetz, C.A., Stehr, C.M., French, B.L., McMillan, B., Wilson, D., Reed, L., Lynch, K.D., Damm, S., Davis, J.W., and Collier, T.K. 2011. Recurrent Die-Offs of Adult Coho Salmon Returning to Spawn in Puget Sound Lowland Urban Streams. PLOSONE Vol 6 Issue 12.

Sharma, R. and R. Hilborn. 2001. Empirical relationships between watershed characteristics and Coho Salmon (*Oncorhynchus kisutch*) smolt abundance in 14 western Washington streams. Can. J. Fish. Aquat. Sci. 58: 1453-1463.

Sharma, R., Cooper, A.B., and R. Hilborn, 2005. A quantitative framework for the analysis of habitat and hatchery practices on Pacific Salmon. Ecological Modelling 183: 231-250.

Simpson, K., Chamberlain, M., Fagan, J., Tanasichuk, R.W., and Dobson, D. Forecast for southern and central British Columbia Coho Salmon in 2004. 2004. DFO Can. Sci. Advis. Sec. 2004/135. viii+69 p. (Accessed July 12, 2015)

Slaney, T.L., K.D. Hyatt, T.G. Northcote, and R.J. Fielden, 1996. Status of Anadromous Salmon and Trout in British Columbia and Yukon. Fisheries, 21(10): 20-35.

Spiegelhalter, D.J., Best, N.G., Carlin, B.R., and A. van der Linde. 2002. Bayesian measures of model complexity and fit. J. Roy. Stat. Soc. B 64: 583-616.

Spiegelhalter, D.J., Thomas A., Best, N.G., and Lunn, D. 1999. WinBUGS User Manual: Version 1.4. Cambridge: MRC Biostatistics Unit, 60 p.

Strahler, A.N. 1957. Quantitative analysis of watershed geomorphology. Trans. Am. Geophys. Union 38: 913-920.

Stuart, T. A. 1962. The leaping behaviour of salmon and trout at falls and obstructions. Department of Agriculture and Fisheries for Scotland, Freshwater and Salmon Fisheries Research Report 28, Edinburgh.

Sturtz, S., Legges U., and Gelman A. 2005. R2WinBGS: a package for running WinBUGS from R. Journal of statistical software 3: 1-16.

10. TABLES

Table 1. Average smolt production, accessible length and years of data for 22 rivers within the EVI-GS, GSM, HS-BI and LFR CUs.

MU	CU	Stream Name	Average Production	Accessible Length (km)	Yield per km	Years of Data
GS-VI	EVI-GS	Black Creek	59,082	46	1,299	27
		Cowichan	289,255	391	740	9
		Englishman	44,607	59	754	9
		Little	11,767	17	689	13
		Millard	3,841	4	917	14
		Morrison	7,106	9	784	9
		Quinsam	57,521	94	609	27
		Simms	6,198	14	458	4
		Tsolum	31,808	92	344	7
		Waterloo	1,542	2	866	9
		Willow	9,810	16	621	4
		Woods	1,441	10	145	11
		Kirby	6,326	2	2,636	5
		Bush	2,219	2	1,305	6
		Millstone	9,013	31	289	6
		AVERAGE	**41,074**	**56**	**803**	**167**
GSM	GSM	Myrtle	1,564	8	188	13
		Whittall	869	3	272	4
		AVERAGE	**1,400**	**7**	**208**	**17**
	HS-BI	Cheakamus	113,119	37	3,041	11
		Seymour	71,115	30	2,355	5
		AVERAGE	**99,993**	**35**	**2,826**	**16**
LFR	LFR	Coquitlam	27,205	24	1,158	11
		S. Alouette	35,851	45	794	14
		Salmon	120,904	123	983	22
		AVERAGE	**73,639**	**77**	**968**	**47**

Table 2. Smolts produced per spawner where paired data is available.

CU	Stream Name	Average Production*	Average Spawners^	Smolts per Spawner			Start Year	End Year	Years of Paired Escapement and Smolt Data
				Average	Min	Max			
EVI-GS	Black Creek	57,286	2,879	34	7	87	1990	2010	20
	Englishman	45,330	3,781	20	5	73	1999	2008	7
	Millard	5,985	122	52	17	119	1998	2004	7
	Waterloo	1,945	117	23	8	43	2000	2004	5
	Woods	1,128	72	18	6	53	1997	2006	9
GSM	Myrtle	1,577	30	58	16	132	2000	2010	10
LFR	Salmon	85,625	3,947	25	12	57	1993	2007	10
AVERAGE		**35,247**	**3,164**	**33**	**5**	**132**	**1990**	**2010**	**68**

* With paired spawner data - thus this average is different from that in Table 1.

^ Where escapement data has nuSEDS estimate quality rating Type-IV or better.

Table 3. Exploitation rates and marine survival estimates of wild Coho Salmon from Black Creek and Myrtle River, 1983-2010.

Brood Year	Return Year	Black Creek		Myrtle	
		Wild, StGeo		Wild, StGeo	
		ER	Survival	ER	Survival
1983	1986	72.7%	12.5%	-	-
1984	1987	84.7%	11.5%	-	-
1985	1988	67.6%	13.4%	-	-
1986	1989	69.7%	11.5%	-	-
1987	1990	71.3%	12.9%	-	-
1988	1991	67.7%	8.0%	-	-
1989	1992	76.7%	12.5%	-	-
1990	1993	73.9%	5.4%	-	-
1991	1994	79.0%	5.9%	-	-
1992	1995	56.7%	4.5%	-	-
1993	1996	70.3%	3.4%	-	-
1994	1997	54.1%	4.9%	-	-
1995	1998	3.0%	4.5%	-	-
1996	1999	3.0%	1.7%	-	-
1997	2000	3.0%	2.2%	-	-
1998	2001	4.6%	7.4%	4.6%	2.9%
1999	2002	5.9%	4.9%	5.9%	2.8%
2000	2003	4.3%	3.0%	4.3%	1.4%
2001	2004	4.3%	4.4%	4.3%	2.5%
2002	2005	4.4%	1.7%	4.4%	0.5%
2003	2006	4.4%	1.4%	4.4%	1.1%
2004	2007	4.2%	2.5%	4.2%	0.2%
2005	2008	5.8%	0.6%	5.8%	1.6%
2006	2009	3.8%	2.5%	4.3%	4.0%
2007	2010	6.5%	1.6%	6.5%	1.6%
2008	2011	5.2%	1.3%	5.2%	1.2%
2009	2012	4.5%	1.4%	4.5%	3.0%
2010	2013	3.9%	2.4%	NA	
2011	2014	NA		NA	

Table 4. Indicator streams identified for escapement to the EVI-GS and GSM CUs, 1990-2013. Escapement data quality rating obtained from nuSEDS.

CU	Stream Name	Percent of Years Where Escapement Data Quality is Type-IV or Better
EVI-GS	Black Creek Coho	88%
EVI-GS	Puntledge River Coho	100%
EVI-GS	Qualicum River Coho	88%
EVI-GS	Mesachie River Coho	85%
EVI-GS	Oliver Creek Coho	73%
EVI-GS	Patricia Creek Coho	73%
EVI-GS	Richards Creek Coho	69%
EVI-GS	Robertson River Coho	77%
GSM	Lang Creek Coho	88%
GSM	Sliammon Creek Coho	88%

Table 5. Exploitation rate and marine survival estimates for hatchery-released enhanced fry in EVI-GS and GSM CUs, 1983-2011.Only years with data have been included. (Joan Bateman, DFO, Oceans, Habitat and Enhancement,, Vancouver, BC)

		EVI-GS		GSM	
Brood Year	Release Stage	ER	Survival	ER	Survival
1990	Fed Fry	99.8%	0.9%	-	-
1991	Fed Fry	84.4%	0.7%	-	-
1992	Fed Fry	52.3%	0.8%	-	-
1993	Fed Fry	66.1%	0.3%	-	-
1994	Fed Fry	30.1%	0.8%	-	-
1995	Fed Fry	8.7%	0.2%	-	-
1996	Fed Fry	5.5%	1.1%	-	-
1997	Fed Fry	0.0%	0.5%	-	-
1998	Fed Fry	0.0%	0.1%	-	-
1999	Fed Fry	7.4%	0.5%	-	-
2000	Fed Fry	0.0%	0.2%	-	-
2007	Fed Fry	0.0%	0.1%	-	-
2009	Fed Fry	15.8%	0.5%	-	-
2010	Fed Fry	41.6%	0.3%	-	-
2011	Fed Fry	100.0%	0.0%	-	-
1990	Fed Fall	100%	0.6%	100%	4.4%

Table 6. Exploitation rate and marine survival estimates for hatchery-released smolts in the EVI-GS CU, 1983-2011. (Steve Baillie, DFO, South Coast, Stock Assessment, Nanaimo, BC).

Brood Year	Big Qualicum (BQ)		Quinsam (QUI)		Average (BQ + QUI)		Goldstream*	
	ER	Survival	ER	Survival	ER	Survival	ER	Survival
1983	-	-	72.6%	9.2%	72.6%	9.2%	-	-
1984	-	-	81.8%	7.8%	81.8%	7.8%	-	-
1985	-	-	77.8%	7.9%	77.8%	7.9%	-	-
1986	-	-	69.0%	10.6%	69.0%	10.6%	-	-
1987	67.8%	4.3%	83.0%	7.8%	75.4%	6.0%	-	-
1988	68.9%	6.2%	66.9%	4.2%	67.9%	5.2%	-	-
1989	75.8%	5.9%	79.0%	5.9%	77.4%	5.9%	-	-
1990	73.6%	6.7%	75.7%	3.5%	74.7%	5.1%	-	-
1991	65.2%	6.9%	73.5%	2.3%	69.3%	4.6%	-	-
1992	54.6%	2.9%	61.9%	2.5%	58.2%	2.7%	-	-
1993	56.6%	1.6%	41.0%	1.4%	48.8%	1.5%	-	-
1994	33.5%	1.4%	39.1%	1.2%	36.3%	1.3%	-	-
1995	4.5%	0.4%	5.0%	1.0%	4.8%	0.7%	-	-
1996	4.3%	1.3%	5.1%	0.7%	4.7%	1.0%	23.4%	0.5%
1997	3.8%	1.3%	5.0%	1.2%	4.4%	1.2%	20.2%	1.0%
1998	6.9%	1.2%	6.5%	1.6%	6.7%	1.4%	46.1%	3.0%
1999	9.9%	1.0%	8.6%	1.4%	9.2%	1.2%	15.8%	0.4%
2000	21.7%	0.8%	21.8%	1.2%	21.8%	1.0%	62.9%	3.7%
2001	22.6%	1.4%	23.8%	1.5%	23.2%	1.5%	28.9%	2.2%
2002	11.1%	0.1%	36.5%	0.5%	23.8%	0.3%	90.4%	1.0%
2003	6.6%	0.1%	32.7%	0.3%	19.6%	0.2%	-	-
2004	33.1%	0.5%	43.5%	1.1%	38.3%	0.8%	83.6%	0.8%
2005	10.7%	0.6%	4.7%	0.7%	7.7%	0.6%	68.1%	0.3%
2006	17.9%	0.4%	15.0%	1.5%	16.5%	1.0%	56.4%	1.3%
2007	11.1%	0.6%	10.3%	0.9%	10.7%	0.7%	37.9%	0.7%
2008	8.0%	0.9%	30.1%	1.1%	19.0%	1.0%	49.0%	0.8%
2009	32.2%	1.8%	33.9%	1.2%	33.0%	1.5%	23.6%	0.8%
2010	26.5%	1.8%	33.6%	2.1%	30.1%	1.9%	65.6%	1.6%
2011	11.5%	0.9%	17.2%	0.7%	14.4%	0.8%	26.8%	0.9%

* Goldstream exploitation rate estimate is used for calculation of Enhanced Return for all "Area 17S" releases (see Appendix 4).

Table 7. Predicted average number of Coho Salmon smolts required to seed available habitat and the required number of spawners to produce these smolts. Spawner confidence intervals are carried forward from smolt estimation confidence limits with no additional variance added to account for other uncertainties (e.g. smolts produced per spawner, fecundity, gradient, stream order, etc.).

MU	CU	Streams (N)	Available Habitat (km)	Total Smolts			Total Spawners		
				Average	Lower CI	Upper CI	Average	Lower CI	Upper CI
GSM	GSM	48	367	395,603	304,459	486,746	11,968	9,226	14,750
	HS-BI	46	520	751,868	557,442	946,294	22,784	16,892	28,676
MU Total*		94	887	1,147,471	997,780	1,297,162	34,752	30,236	39,308
LFR	LFR	93	1370	1,484,479	1,390,584	1,578,373	46,005	42,139	47,829
	LILL	19	721	910,977	567,481	1,254,473	27,605	17,196	38,014
	BB	4	481	608,082	-	-	18,427	-	-
MU Total*		116	2572	3,003,538	2,821,311	3,185,764	92,037	85,494	96,538
GS-VI	EVI-GS	103	1765	1,603,226	1,522,169	1,684,282	49,422	46,126	51,039

** MU totals are not the sum of data for each CU within the MU, but are calculated for each MU separately.*

Table 8. Estimates of stream length, smolts produced and spawners required for the four largest contributing streams in each CU.

MU	CU	Watershed	Stream Length (m)	Smolts Produced	Spawners	Spawners per km	Percent of Total CU Spawners	Percent of Available CU Habitat
GSM	GSM	Toba River	170,220	217,727	6,598	39	55%	46%
GSM	GSM	Little Toba River	33,520	36,350	1,102	33	9%	9%
GSM	GSM	Ruby Creek	21,390	22,175	672	31	6%	6%
GSM	GSM	Quatam River	15,160	15,187	460	30	4%	4%
Subtotal			**240,290**	**291,439**	**8,831**	**37**	**74%**	**66%**
GSM	HS-BI	Squamish River	337,380	463,101	14,033	42	62%	65%
GSM	HS-BI	Cheakamus River	37,200	113,119	3,428	92	15%	7%
GSM	HS-BI	Seymour River	30,210	71,139	2,156	71	9%	6%
GSM	HS-BI	Indian River	20,170	20,788	630	31	3%	4%
Subtotal			**424,960**	**668,148**	**20,247**	**48**	**89%**	**82%**
LFR	LFR	Chilliwack/Vedder River	151,310	191,214	5,794	38	13%	11%
LFR	LFR	Pitt River	126,330	156,723	4,749	38	10%	9%
LFR	LFR	Harrison River	86,680	103,479	3,136	36	7%	6%
LFR	LFR	Salmon River	107,060	105,235	4,209	39	9%	8%
Subtotal			**471,380**	**556,651**	**17,889**	**38**	**39%**	**34%**
LFR	LILL	Lillooet River - Upper	311,320	423,786	12,842	41	47%	43%
LFR	LILL	Lillooet River - Lower	189,600	245,218	7,431	39	27%	26%
LFR	LILL	Birkenhead River	104,450	127,085	3,851	37	14%	14%
LFR	LILL	Ryan River	29,110	31,124	943	32	3%	4%
Subtotal			**634,480**	**827,214**	**25,067**	**40**	**91%**	**88%**
LFR	BB	Nicomekl River	201,290	261,945	7,938	39	43%	42%
LFR	BB	Serpentine River	184,720	238,267	7,220	39	39%	38%
LFR	BB	Campbell River	67,440	78,483	2,378	35	13%	14%
LFR	BB	Murray Creek	27,630	29,387	891	32	5%	6%
Subtotal			**481,080**	**608,082**	**18,427**	**38**	**100%**	**100%**
GS-VI	EVI-GS	Cowichan River	391,830	289,869	8,784	22	18%	22%
GS-VI	EVI-GS	Puntledge River	138,330	173,211	5,249	38	11%	8%
GS-VI	EVI-GS	Nanaimo River	123,980	153,512	4,652	38	9%	7%
GS-VI	EVI-GS	Quinsam River	94,360	57,472	1,742	18	4%	5%
Subtotal			**748,500**	**674,065**	**20,426**	**27**	**41%**	**42%**

Table 9. Wild spawners and recruits for GSM and EVI-GS CUs, 1990-2013.

EVI-GS

Return Year	Indicator Stream Esc	AF 1	Adj Sum 1	AF 2	Total Esc	Brood Take	Total S	Total Enh Origin Esc	Enh Cont	Wild S	ER	Wild Recruits	SR	Wild Smolts*
1990	27,606	1	27,606	2.436	67,257	15,396	50,487	46,981	0.70	15,220	71%	53,032	12.9%	411,916
1991	39,766	1	39,766	2.436	96,883	20,230	77,000	63,412	0.65	26,602	68%	82,358	8.0%	1,027,635
1992	26,568	1	26,568	2.436	64,728	17,355	47,776	52,809	0.82	8,798	77%	37,758	12.5%	302,631
1993	44,449	1	44,449	2.436	108,292	34,827	73,913	45,652	0.42	42,754	74%	163,808	5.4%	3,047,874
1994	39,614	1	39,614	2.436	96,512	30,438	65,933	46,508	0.48	34,161	79%	162,670	5.9%	2,735,523
1995	45,699	1	45,699	2.436	111,337	33,451	78,074	46,886	0.42	45,196	57%	104,379	4.5%	2,296,636
1996	24,451	1	24,451	2.436	59,570	18,400	41,522	31,633	0.53	19,473	70%	65,565	3.4%	1,945,037
1997	28,171	1	28,171	2.436	68,634	21,242	46,900	46,196	0.67	15,332	54%	33,404	4.9%	682,922
1998	25,007	1	25,007	2.436	60,925	9,910	50,875	28,114	0.46	27,399	3%	28,246	4.5%	621,657
1999	29,695	1	29,695	2.436	72,347	22,565	50,193	51,087	0.71	14,749	3%	15,205	1.7%	893,024
2000	26,720	1	26,720	2.946	78,719	17,889	61,234	52,488	0.67	20,405	3%	21,036	2.2%	964,975
2001	64,933	1	64,933	2.946	191,297	31,472	159,045	59,847	0.31	109,288	5%	114,558	7.4%	1,556,553
2002	67,022	1	67,022	2.946	197,452	25,000	173,362	49,426	0.25	129,966	6%	138,115	4.9%	2,794,239
2003	30,410	1	30,410	2.946	89,590	6,977	82,402	35,977	0.40	49,312	4%	51,528	3.0%	1,744,785
2004	47,143	1	47,143	2.946	138,887	13,119	126,023	48,555	0.35	81,965	4%	85,648	4.4%	1,966,499
2005	7,383	1	7,383	2.946	21,751	3,563	18,318	7,153	0.33	12,294	4%	12,860	1.7%	737,724
2006	6,203	1	6,203	2.946	18,275	2,627	15,649	4,682	0.26	11,640	4%	12,175	1.4%	897,077
2007	12,728	1	12,728	2.946	37,498	2,728	34,679	11,907	0.32	23,667	4%	24,705	2.5%	1,002,082
2008	8,223	1.009	8,296	2.946	24,441	2,967	21,474	11,566	0.47	11,311	6%	12,008	0.6%	1,912,016
2009	22,549	1.046	23,577	2.946	69,461	7,021	62,440	21,275	0.31	43,316	4%	45,027	2.5%	1,827,047
2010	18,754	1.003	18,805	2.648	49,801	5,484	44,317	14,793	0.30	31,153	7%	33,319	1.6%	2,082,414
2011	22,665	1.003	22,727	2.648	60,186	12,832	47,354	17,313	0.29	33,732	5%	35,583	1.3%	2,737,115
2012	14,412	1.198	17,272	2.648	45,741	7,983	37,758	25,506	0.56	16,703	5%	17,490	1.4%	1,249,298
2013	19,663	1.195	23,489	2.648	62,204	13,484	48,720	28,509	0.46	26,390	4%	27,461	2.4%	1,144,224
Average	**29,160**		**29,489**		**78,824**	**15,707**	**63,144**	**35345**	**0.46**	**35,451**	**26%**	**57,414**		**1,524,204**
Max	**67,022**		**67,022**		**197,452**	**34,827**	**173,362**	**63412**	**0.82**	**129,966**	**79%**	**163,808**		**3,047,874**
Min	**6,203**		**6,203**		**18,275**	**2,627**	**15,649**	**4682**	**0.25**	**8,798**	**3%**	**12,008**		**302,631**

Table 9. (Continued)

GSM

Return Year	Indicator Stream Esc	AF 1	Adj Sum 1	AF 2	Total Esc	Brood Take	Total S	Total Enh Origin Esc	Enh Contrib	Wild S	ER	Wild Recruits	SR	Wild Smolts*
1990	6,586	1	6,586	1.730	11,393	584	10,809	1,881	0.17	9,025	71%	31,445	12.9%	244,244
1991	5,647	1	5,647	1.730	9,769	837	8,932	3,358	0.34	5,862	68%	18,147	8.0%	226,436
1992	2,244	1	2,244	1.730	3,882	620	3,262	766	0.20	2,618	77%	11,236	12.5%	90,057
1993	4,511	1	4,511	1.730	7,804	771	7,033	1,634	0.21	5,560	74%	21,302	5.4%	396,346
1994	3,308	1	3,308	1.730	5,723	1,748	3,975	1,849	0.32	2,690	79%	12,810	5.9%	215,414
1995	4,571	1	4,571	1.730	7,907	689	7,218	954	0.12	6,347	57%	14,659	4.5%	322,539
1996	4,038	1	4,038	1.730	6,985	986	5,999	1,373	0.20	4,820	70%	16,228	3.4%	481,423
1997	929	1	929	1.730	1,607	469	1,138	512	0.32	775	54%	1,689	4.9%	34,531
1998	1,783	1	1,783	1.730	3,084	149	2,935	738	0.24	2,233	3%	2,302	4.5%	50,658
1999	1,738	1	1,738	1.730	3,007	184	2,823	688	0.23	2,177	3%	2,244	1.7%	131,793
2000	1,352	1	1,352	4.162	5,627	100	5,527	942	0.17	4,601	3%	4,744	2.2%	217,607
2001	2,550	1	2,550	4.162	10,612	98	10,514	12	0.05	10,007	5%	10,490	2.9%	366,052
2002	1,135	1	1,135	4.162	4,724	-	4,724	222	0.05	4,502	6%	4,784	2.8%	167,948
2003	1,906	1	1,906	4.162	7,932	-	7,932	1,180	0.15	6,753	4%	7,056	1.4%	490,876
2004	1,460	1	1,460	4.162	6,076	-	6,076	443	0.07	5,633	4%	5,887	2.5%	235,779
2005	1,237	1	1,237	4.162	5,148	-	5,148	123	0.02	5,025	4%	5,256	0.5%	993,038
2006	868	1	868	4.162	3,612	-	3,612	14	0.00	3,598	4%	3,763	1.1%	350,608
2007	1,567	1	1,567	4.162	6,521	-	6,521	-	0.00	6,521	4%	6,807	0.2%	3,843,089
2008	284	1	284	4.162	1,182	-	1,182	0	0.00	1,182	6%	1,255	1.6%	80,343
2009	947	1	947	4.162	3,941	-	3,941	1	0.00	3,941	4%	4,096	4.0%	103,039
2010	2,085	1	2,085	2.875	5,994	-	5,994	236	0.04	5,759	7%	6,159	1.6%	384,941
2011	2,496	1	2,496	2.875	7,176	420	6,756	119	0.02	6,644	5%	7,009	1.2%	584,072
2012	1,163	1	1,163	2.875	3,344	307	3,037	50	0.01	2,991	5%	3,132	3.0%	104,408
2013	4,501	1	4,501	2.875	12,941	471	12,470	42	0.00	12,429	4%	12,934	NA	NA
Average	**2,454**		**2,454**		**6,083**	**351**	**5,732**	**735**	**0.12**	**5,071**	**26%**	**8,976**		**439,793**
Max	**6,586**		**6,586**		**12,941**	**1,748**	**12,470**	**3358**	**0.34**	**12,429**	**79%**	**31,445**		**3,843,089**
Min	**284**		**284**		**1,182**	**-**	**1,138**	**0**	**0.00**	**775**	**3%**	**1,255**		**34,531**

Table 9 Notes:

* Estimated as Wild Recruits/Survival

GSM Survival Rate (SR) highlighted grey is the measured rate from Black Creek and assumes equal survival. Rates for years 2002-2012 are measured survival at Myrtle Creek.

AF 1 (Adjustment Factor 1) adjusts observed escapement to indicator streams to account for indicator streams that were not assessed in that year.

AF 2 (Adjustment Factor 2) adjusts escapement to indicator streams (Adj Sum1) to account for escapement to all non-indicator streams.

All adjustment factors are based on the relative contributions each stream makes to its aggregate group, when and where data is available. A critical assumption is that streams co-vary in abundance. Adjustment factors can change as new (future) data becomes available.

Esc: Escapement

S: Spawners

Enh: Enhanced

Contrib: Contribution

ER: Exploitation Rate

SR: Survival Rate

Table 10. Southern BC Coho Salmon benchmarks for EVI-GS and GSM CUs derived from the stock-recruit analysis. Escapement needed to recover to Smsy in one generation (Sgen, in thousands of fish), escapement needed to achieve MSY (Smsy, in thousands of fish), and harvest rate to achieve MSY (Umsy) for EVI-GS and GSM Coho Salmon CUs based on Beverton-Holt (BH) and Logistic Hockeye Stick (LHS) recruitment models. Results are presented for spawner-adult recruit and spawner-smolt recruit fits, where benchmarks for the latter group were computed assuming 1%, 2.5%, and 5.0% marine survival. Model results also differ by the amount of information in the prior (prCV) for maximum recruitment. MU, LCL, and UCL denote the mean of the posterior values and lower and upper 95% credible intervals respectively.

EVI-GS

Model	Recruit Type	Marine Survival	prCV	Umsy			Smsy			Sgen		
				MU	LCL	UCL	MU	LCL	UCL	MU	LCL	UCL
BH	Adult	0.027	0.1	0.67	0.51	0.74	10.5	8.0	13.0	1.6	0.8	4.0
			0.3	0.67	0.50	0.73	10.6	7.0	16.0	1.6	0.7	4.6
			0.6	0.67	0.50	0.73	10.8	7.0	18.0	1.7	0.6	5.2
	Smolt	0.01	0.1	0.25	0.11	0.31	3.1	2.0	4.0	2.1	1.5	2.8
			0.3	0.24	0.10	0.31	3.5	2.0	5.0	2.4	1.4	3.4
			0.6	0.24	0.10	0.31	3.6	2.0	5.0	2.5	1.4	3.7
		0.025	0.1	0.52	0.44	0.56	10.5	9.0	12.0	3.2	2.4	4.6
			0.3	0.52	0.43	0.56	12.0	9.0	16.0	3.7	2.4	5.9
			0.6	0.52	0.43	0.56	12.6	9.0	18.0	4.0	2.5	6.6
		0.05	0.1	0.66	0.60	0.69	18.9	16.0	23.0	2.8	2.1	4.4
			0.3	0.66	0.60	0.69	21.5	15.0	30.0	3.3	2.1	5.5
			0.6	0.66	0.60	0.69	22.8	15.0	33.0	3.5	2.1	6.2
LHS	Adult	0.027	0.1	0.35	0.12	0.54	20.5	15.0	26.0	11.6	6.0	16.2
			0.3	0.36	0.13	0.55	24.0	13.0	36.0	13.0	6.2	20.6
			0.6	0.37	0.14	0.57	27.3	13.0	47.0	14.3	6.3	26.0
	Smolt	0.01	0.1	0.00	0.00	0.05	1.1	1.0	3.0	1.5	1.0	2.8
			0.3	0.00	0.00	0.07	1.2	1.0	5.0	1.5	1.0	4.6
			0.6	0.01	0.00	0.10	1.5	1.0	8.0	1.8	1.0	6.8
		0.025	0.1	0.30	0.12	0.47	17.5	12.0	22.0	10.9	6.9	14.2
			0.3	0.33	0.16	0.48	22.0	13.0	32.0	12.9	7.7	18.1
			0.6	0.35	0.16	0.50	24.8	14.0	37.0	13.9	8.1	20.4
		0.05	0.1	0.56	0.44	0.67	30.6	23.0	38.0	9.6	4.9	15.8
			0.3	0.58	0.46	0.68	36.6	24.0	51.0	10.7	5.5	17.5
			0.6	0.59	0.46	0.70	40.4	25.0	57.0	11.3	5.6	19.2

Table 10 cont'd.

GSM

Model	Recruit Type	Marine Survival	prCV	Umsy			Smsy			Sgen		
				MU	LCL	UCL	MU	LCL	UCL	MU	LCL	UCL
BH	Adult	0.027	0.1	0.54	0.31	0.74	2.7	2.0	3.0	0.8	0.2	1.7
			0.3	0.60	0.36	0.77	2.2	1.0	3.0	0.5	0.1	1.6
			0.6	0.63	0.39	0.78	1.9	1.0	3.0	0.4	0.1	1.4
	Smolt	0.01	0.1	0.08	0.00	0.24	1.0	1.0	1.0	1.0	0.7	1.7
			0.3	0.07	0.00	0.23	1.0	1.0	1.0	1.0	0.7	1.6
			0.6	0.06	0.00	0.23	1.0	1.0	1.0	1.0	0.7	1.7
		0.025	0.1	0.47	0.29	0.58	2.3	2.0	3.0	0.9	0.5	1.5
			0.3	0.47	0.29	0.58	2.2	2.0	3.0	0.9	0.5	1.8
			0.6	0.47	0.27	0.59	2.2	1.0	4.0	0.9	0.3	2.1
		0.05	0.1	0.62	0.50	0.69	4.5	4.0	6.0	0.9	0.5	1.8
			0.3	0.63	0.50	0.70	4.2	3.0	7.0	0.8	0.4	2.0
			0.6	0.63	0.48	0.70	4.2	2.0	8.0	0.8	0.3	2.4
LHS	Adult	0.027	0.1	0.42	0.13	0.68	4.5	3.0	6.0	2.2	0.6	3.9
			0.3	0.47	0.18	0.66	3.5	2.0	6.0	1.6	0.5	4.1
			0.6	0.48	0.19	0.66	3.0	2.0	7.0	1.3	0.5	4.3
	Smolt	0.01	0.1	0.05	0.00	0.27	1.1	1.0	2.0	1.2	0.7	2.1
			0.3	0.05	0.00	0.27	1.0	1.0	2.0	1.2	0.7	2.0
			0.6	0.04	0.00	0.26	1.0	1.0	1.0	1.2	0.7	2.0
		0.025	0.1	0.40	0.13	0.62	3.8	3.0	5.0	1.9	0.8	3.2
			0.3	0.42	0.15	0.61	3.3	2.0	5.0	1.6	0.7	3.5
			0.6	0.41	0.16	0.60	3.1	2.0	6.0	1.6	0.6	4.1
		0.05	0.1	0.63	0.44	0.77	6.0	4.0	9.0	1.6	0.5	3.7
			0.3	0.64	0.46	0.76	5.2	3.0	10.0	1.3	0.4	3.7
			0.6	0.64	0.47	0.76	5.0	3.0	12.0	1.3	0.4	4.4

Table 11. Deviance information criteria (DIC) comparing Beverton-Holt (BH) and Logistic Hockey Stick (LHS) models for each conservation unit (CU) and prior distribution of maximum recruitment (prCV). Results are presented for spawner-adult recruit and spawner-smolt recruit fits. Models with lower DIC are considered to have better out-of-sample predictive power. Shaded grey cells indicate substantive model support (i.e., ΔDIC is lower by more than 2 units).

CU	Recruit Type	prCV	DIC		ΔDIC
			BH	LHS	
EVI-GS	Adult	0.1	212	221	-9
		0.3	213	221	-8
		0.6	214	223	-9
	Smolt	0.1	351	364	-13
		0.3	351	363	-12
		0.6	352	363	-11
GSM	Adult	0.1	126	130	-4
		0.3	125	128	-3
		0.6	125	128	-3
	Smolt	0.1	275	279	-4
		0.3	275	278	-3
		0.6	276	278	-2

Table 12. Estimated accessible stream length (m) over a range of gradient limits and minimum stream orders by conservation unit (CU).Grey shading indicates the base case.

		Minimum Stream Order Included				
CU	Gradient	1	2	3	4	Difference (%)
GSM	<8%	366,630	250,500	186,880	153,200	-58%
	<6%	357,170	244,400	182,910	150,600	-58%
	<4%	336,460	230,870	174,630	143,890	-57%
	<2%	310,200	211,650	159,340	130,860	-58%
% Difference from 8% to 2%:		-15%	-16%	-15%	-15%	
LFR	<8%	1,370,100	834,160	567,900	412,130	-70%
	<6%	1,350,060	824,600	563,130	409,270	-70%
	<4%	1,290,160	797,110	550,010	400,690	-69%
	<2%	1,209,340	746,450	514,150	370,220	-69%
% Difference from 8% to 2%:		-12%	-11%	-9%	-10%	
LILL	<8%	721,050	459,480	401,000	331,660	-54%
	<6%	706,370	451,400	395,300	328,240	-54%
	<4%	678,970	433,780	380,320	315,890	-53%
	<2%	633,290	399,050	347,960	285,800	-55%
% Difference from 8% to 2%:		-12%	-13%	-13%	-14%	
ECVI-GS	<8%	1,764,520	1,178,220	858,470	610,020	-65%
	<6%	1,736,590	1,163,400	850,790	606,220	-65%
	<4%	1,664,190	1,119,600	826,320	592,390	-64%
	<2%	1,561,710	1,054,440	782,680	565,760	-64%
% Difference from 8% to 2%:		-11%	-11%	-9%	-7%	
HS-BI	<8%	520,060	325,640	276,050	229,050	-56%
	<6%	506,890	316,150	269,470	225,670	-55%
	<4%	483,620	299,510	256,570	218,990	-55%
	<2%	444,250	271,510	232,230	201,260	-55%
% Difference from 8% to 2%:		-15%	-17%	-16%	-12%	
BB	<8%	481,080	207,920	125,530	60,080	-88%
	<6%	476,510	207,710	125,490	60,040	-87%
	<4%	455,970	205,160	124,960	60,040	-87%
	<2%	426,840	200,100	123,630	59,720	-86%
% Difference from 8% to 2%:		-11%	-4%	-2%	-1%	

Table 13. Percent change in required spawners with change in stream gradient limit and minimum stream order by conservation unit (CU). Grey shaded cells indicate the base case scenario for each CU.

CU	Stream Order	Gradient			
		8	6	4	2
GSM	1	0%	-2%	-8%	-15%
	2	-35%	-37%	-40%	-45%
	3	-50%	-51%	-53%	-58%
LFR	1	0%	-4%	-8%	-14%
	2	-43%	-44%	-45%	-49%
	3	-62%	-62%	-63%	-66%
LILL	1	0%	-2%	-6%	-13%
	2	-40%	-41%	-43%	-48%
	3	-48%	-49%	-51%	-55%
EVI-GS	1	0%	-3%	-8%	-14%
	2	-35%	-36%	-38%	-42%
	3	-52%	-52%	-54%	-57%
HS-BI	1	0%	-3%	-7%	-15%
	2	-40%	-41%	-44%	-50%
	3	-49%	-50%	-53%	-57%
BB	1	0%	-1%	-6%	-12%
	2	-61%	-61%	-61%	-62%
	3	-77%	-77%	-77%	-78%

Table 14. Percent change in required spawners across varying numbers of smolts produced per spawner. Grey cell indicates the base case scenario.

		Smolts produced per Spawner									
CU	MU	20	30	33	40	50	60	70	80	90	100
Each	Each	65%	10%	0%	-17%	-34%	-45%	-53%	-59%	-63%	-67%

Table 15. Comparison of stream lengths used to generate predictive regression (GIS Length) versus other data sources.

Stream Name	Reported Length (km)	Source of Reported Length	GIS Length (km)	Similarity of Reported Length to GIS Length (%)
Waterloo	1.9	DFO	1.8	107%
Whittall	2.6	DFO	3.2	82%
Millard	3.0	DFO	4.2	72%
Myrtle	8.1	DFO	8.3	97%
Morrison	9.6	DFO	9.1	106%
Woods	5.0	DFO	10.0	50%
Little	10.2	DFO	17.1	60%
Simms	8.7	DFO	13.5	64%
Willow	11.3	DFO	15.8	72%
Black Creek	33.0	DFO	45.5	73%
Englishman	39.2	DFO	59.1	66%
Quinsam	54.9	DFO	94.4	58%
Tsolum	57.4	DFO	92.4	62%
Salmon	39.1	DFO	123.0	32%
S. Alouette	14.8	BC Hydro	45.2	33%
Cheakamus	17.0	BC Hydro	37.2	46%
Coquitlam	24.0	BC Hydro	23.5	102%
Seymour	14.0	Metro Vancouver/InStream	30.2	46%
Cowichan*	96.0	DFO	391.0	NA
Kirby	3.1	DFO	2.4	129%
Bush	2.4	DFO	1.7	141%
Millstone	NA	NA	31.2	NA
Average	**22**		**49**	**75%**

* Reported length is for anadromous access above, and including Cowichan Lake.
GIS estimates are for the complete accessible length and include all accessible habitat.

Table 16. Average spawners and 95% credible intervals (Lower CI, Upper CI) as estimated from the Habitat Model and the infilled nuSEDS escapement data, 1990-2013.

	Habitat Model			In-fill Routine		
CU	Average	Lower CI	Upper CI	Average	Lower CI	Upper CI
EVI-GS	49,422	46,126	51,039	35,451	23,131	47,771
GSM	11,968	9,226	14,750	5,071	2,610	6,151

Table 17. Stock-recruit results for each CU and MU using the spawner-smolt recruit data and under assumptions of 1%, 2.5% and 5% marine survival and 0.6 prCV.

			Marine Survival								
			1.0%			2.5%			5.0%		
MU	CU	Metric	Average	Lower CI	Upper CI	Average	Lower CI	Upper CI	Average	Lower CI	Upper CI
GSM	GSM	Umsy	0.04	0	0.26	0.41	0.16	0.6	0.64	0.47	0.76
		Smsy	3,000	2,000	7,000	3,100	2,000	6,000	5,000	3,000	12,000
		Sgen	1,200	700	2,000	1,600	600	4,100	1,300	400	4,400
	HS-BI	All	NA	NA	NA	NA	NA	NA	NA	NA	NA
EC-VI	EVI-GS	Umsy	0.01	0	0.1	0.35	0.16	0.5	0.59	0.46	0.7
		Smsy	1,500	1,000	8,000	24,800	14,000	37,000	40,400	25,000	57,000
		Sgen	1,800	1,000	6,800	13,900	8,100	20,400	11,300	5,600	19,200
LFR	LFR	All	NA	NA	NA	NA	NA	NA	NA	NA	NA
	LILL	All	NA	NA	NA	NA	NA	NA	NA	NA	NA
	BB	All	NA	NA	NA	NA	NA	NA	NA	NA	NA

11. FIGURES

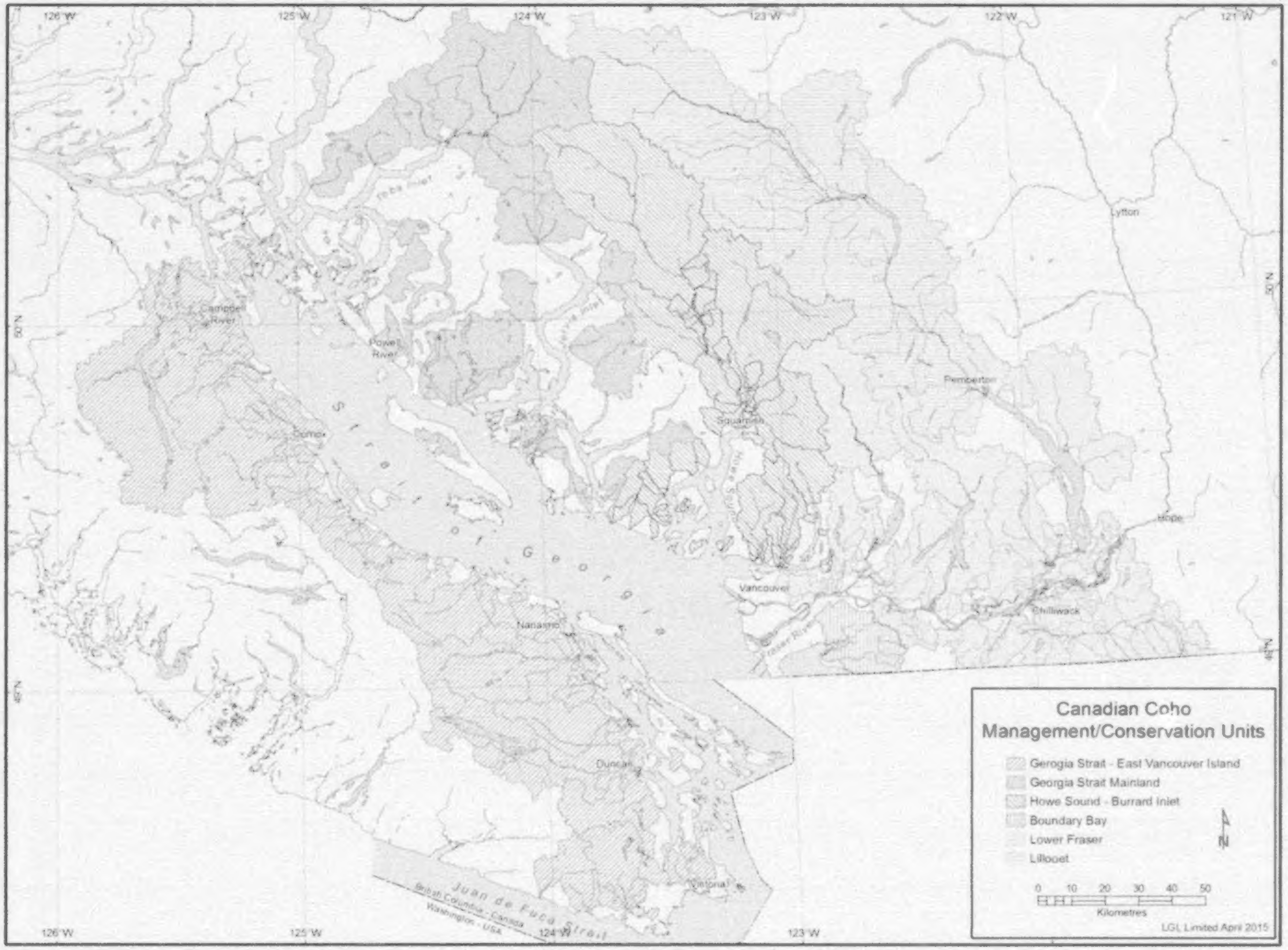
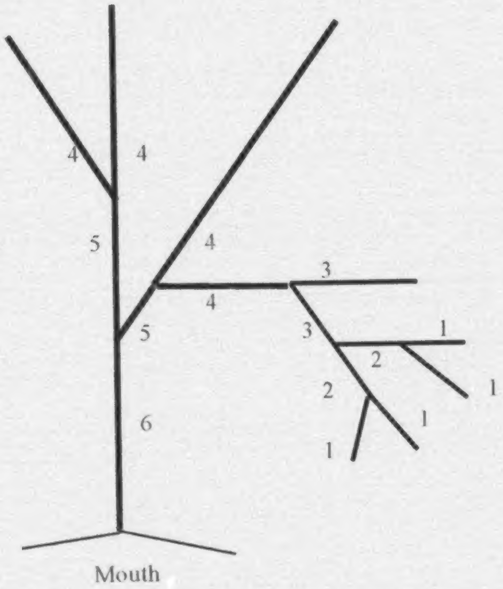

126°W
125°W
124°W
123°W
122°W
121°W
50°N
49°N
Toba Inlet
Campbell River
Powell River
Comox
Strait of Georgia
Squamish
Pemberton
Lytton
Hope
Vancouver
Chilliwack
Nanaimo
Duncan
Victoria
Juan de Fuca Strait
British Columbia - Canada
Washington - USA
Canadian Coho
Management/Conservation Units
Gerogia Strait - East Vancouver Island
Georgia Strait Mainland
Howe Sound - Burrard Inlet
Boundary Bay
Lower Fraser
Lillooet
N
0
10
20
30
40
50
Kilometres
LGL Limited April 2015

Figure 1. Map of GSM, EVI-GS, HS-BI, BB, LFR and LILL CUs of interest and watersheds where Coho Salmon are known to spawn.



4
4
5
4
3
4
3
5
1
2
2
1
6
1
1
Mouth

Figure 2. Schematic drawing of a stream of the 6th order, numbers indicate stream order.

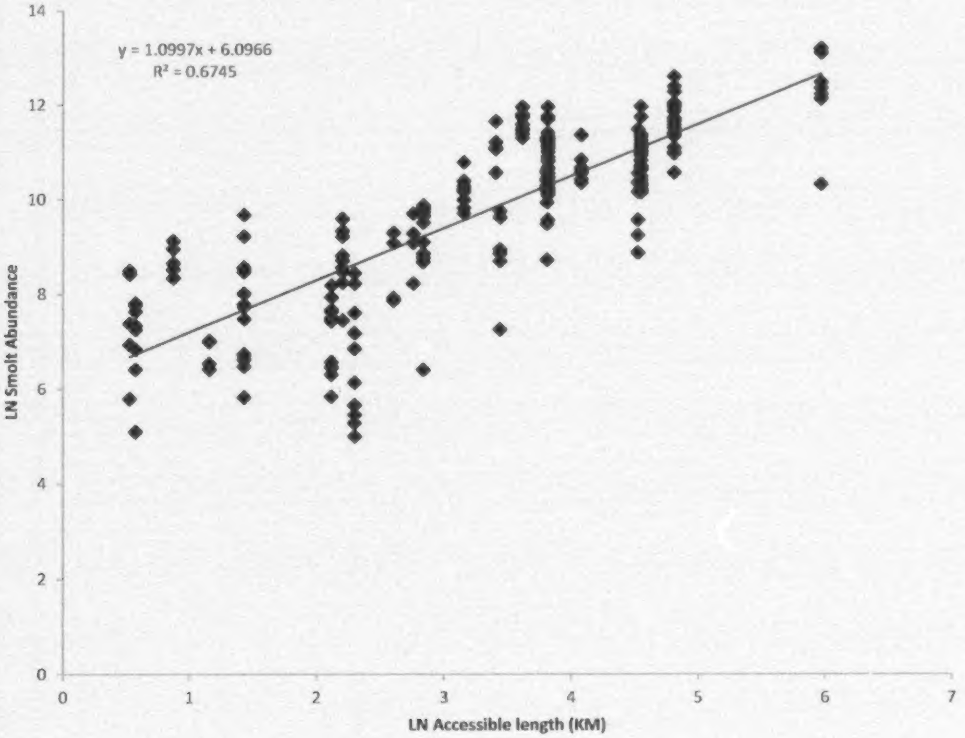


Figure 3. Natural log (LN) average smolt abundance as a function of LN accessible stream length (LN km) for all streams from CUs of interest where data was available.

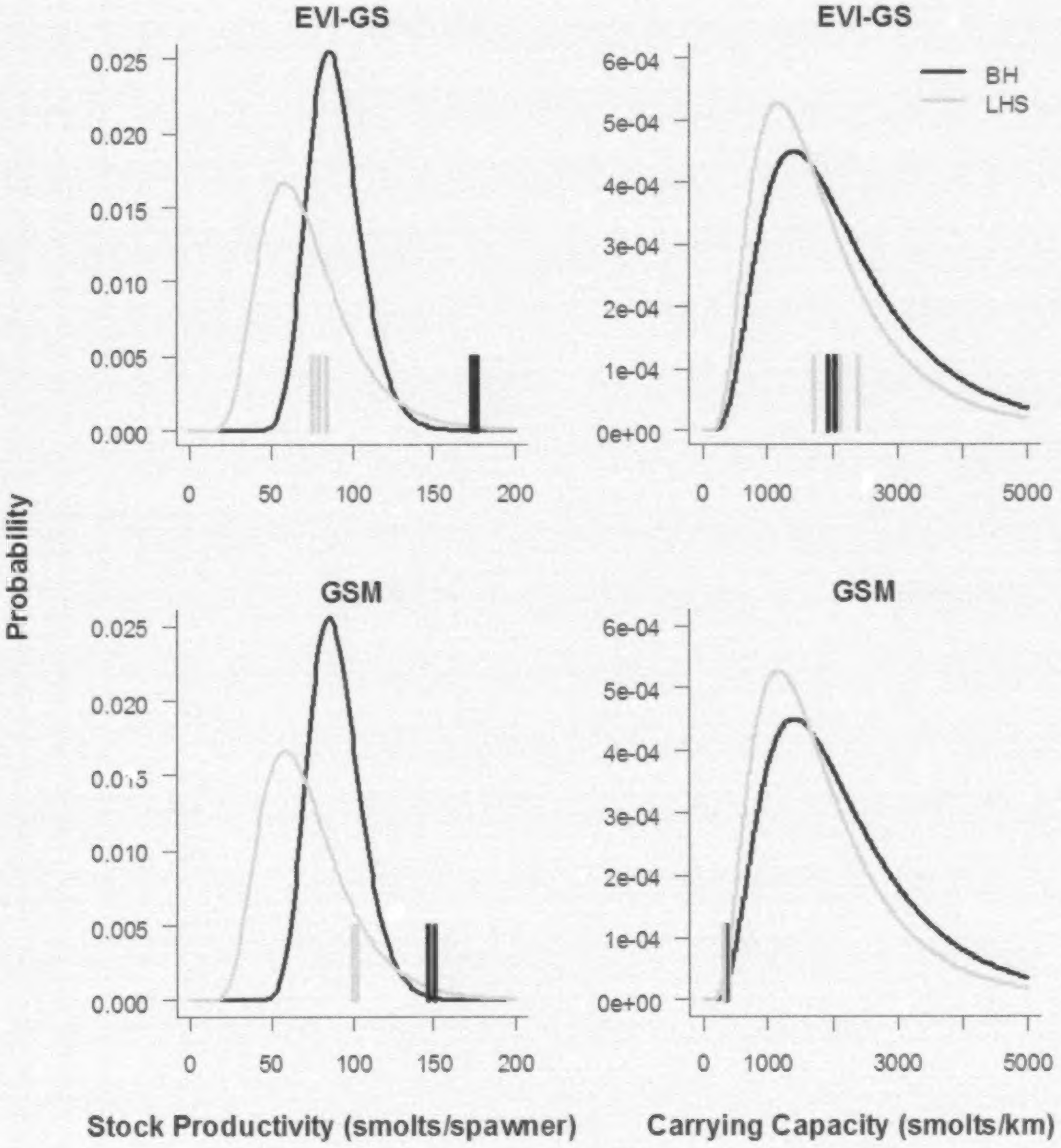


Figure 4. Hyper-distributions of stock productivity and carrying capacity (curved lines) based on a regional analysis of spawner-smolt recruit datasets (Korman and Tompkins 2014) compared to estimates from this study (vertical lines) by CU. For each CU, six estimates are provided (2 stock-recruit model forms for each of 3 levels of information in the prior for carrying capacity). Vertical bars located under the curve indicate support in productivity estimates between the Korman and Tompkins (2014) analysis and ours.

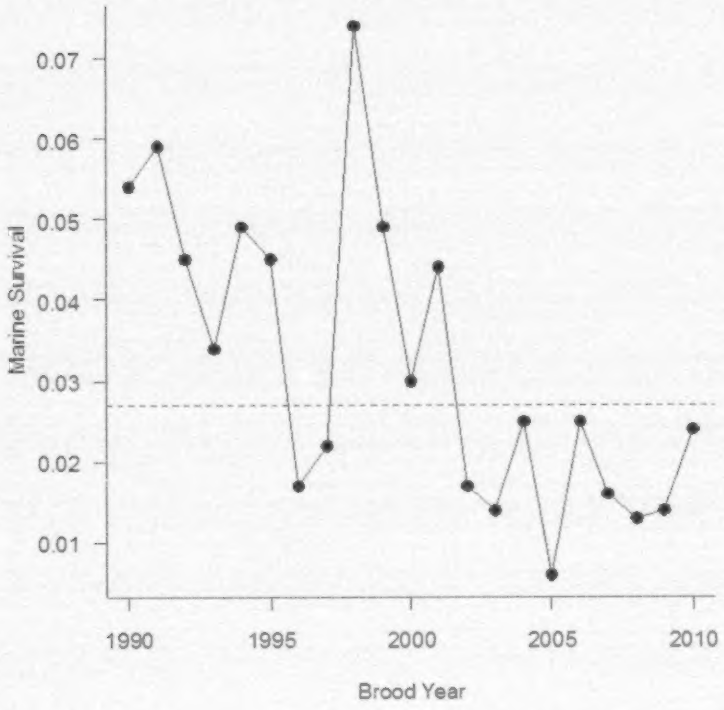


Figure 5. Black Creek smolt-to-adult survival rates for Coho Salmon, 1990-2010. The dashed horizontal line shows the average marine survival, computed from log-transformed values over all years.

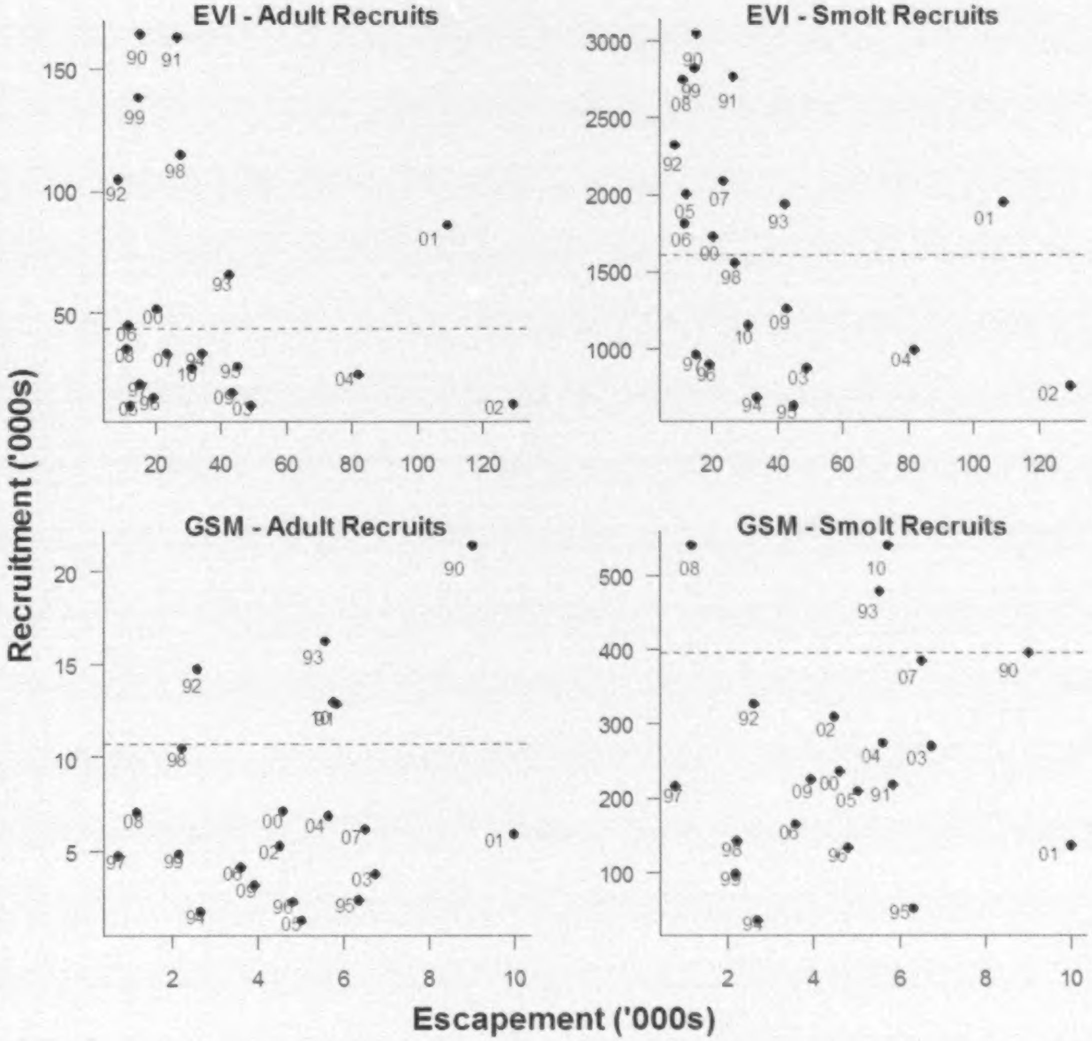


Figure 6. Stock-recruit data for East Vancouver Island (EVI-GS) and Georgia Strait Mainland (GSM) Coho Salmon CUs. Recruitment is expressed based on both adult recruits, and smolt recruits, the latter was estimated though back-calculation based on annual marine survival estimates. Labels beside the data points denote the brood year. Dashed horizontal lines indicate the mean of the prior on maximum recruitment as determined by the Habitat Model.

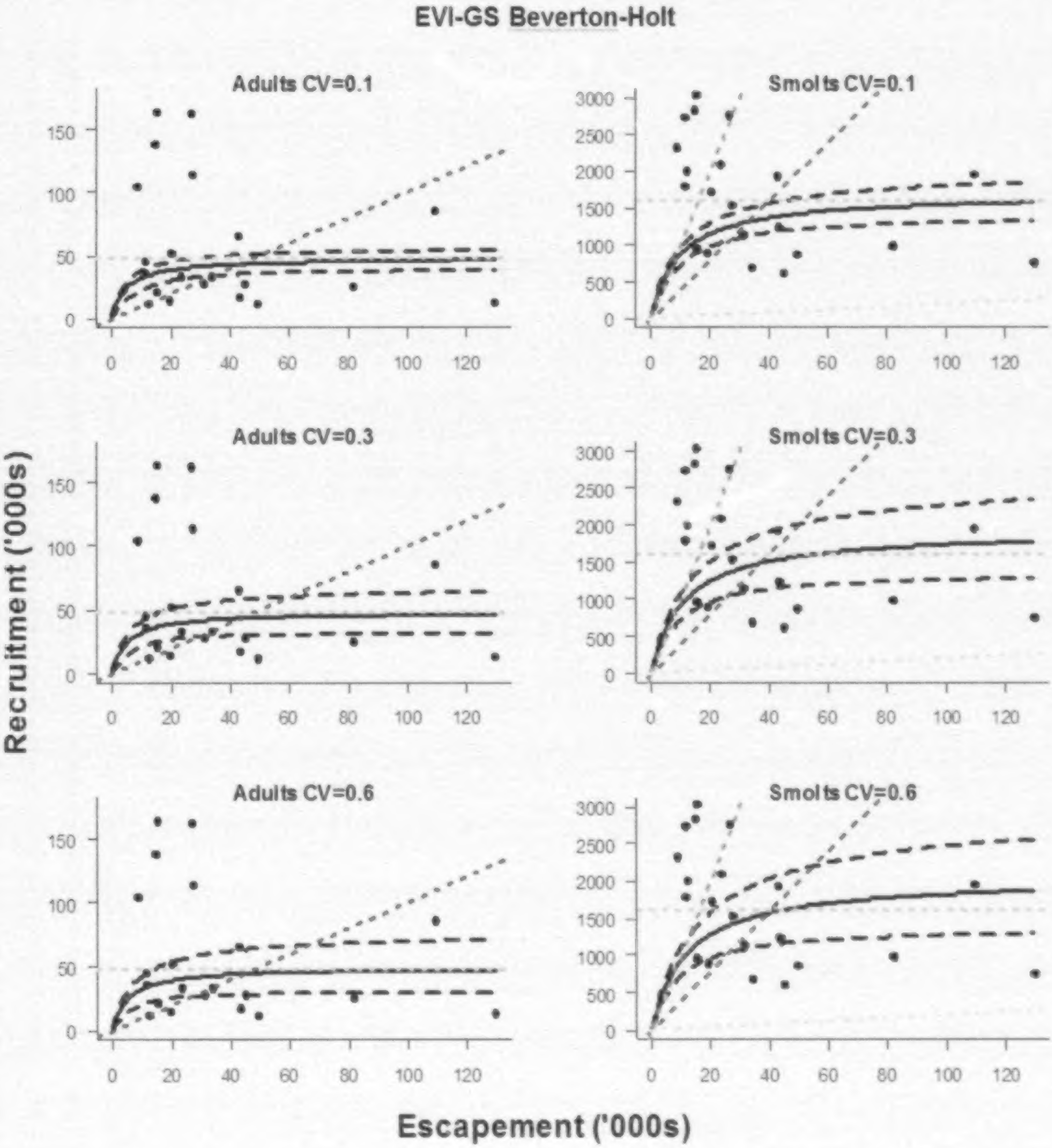


Figure 7. Stock-recruitment relationships for the East Vancouver Island (EVI-GS) Coho Salmon CU based on a Beverton-Holt model fit to spawner-adult recruit (left column) and spawner-smolt recruit (right column) data sets. The solid black line represents the expected relationship based on the mean of parameter estimates from the posterior distributions, and the dashed black lines represent the 95% credible interval. The light gray dashed horizontal line shows the mean of the prior on maximum recruitment. The dashed angled colored lines represent the 1:1 relationship (replacement). For spawner-smolt recruit fits, the slopes of these lines are based on 1% (red), 2.5% (blue), and 5% (green) marine survival rates. Each panel presents results for alternate forms of the prior distribution for maximum recruitment as determined by the amount of information in the prior distribution (CV= coefficient of variation).

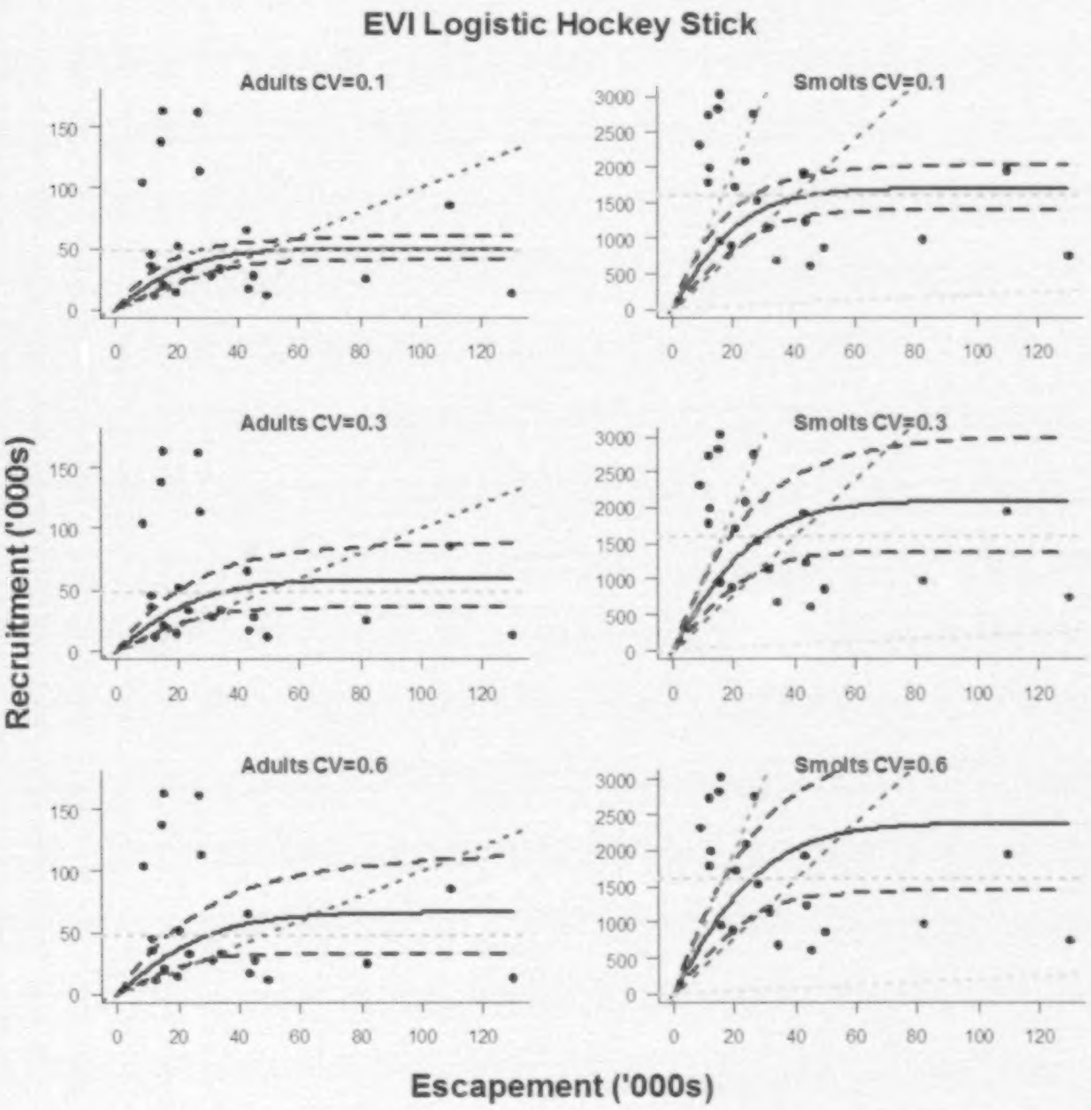


Figure 8. Stock-recruitment relationships for the East Vancouver Island (EVI-GS) Coho Salmon CU based on a Logistic Hockey Stick model fit to spawner-adult recruit (left column) and spawner-smolt recruit (right column) data sets. See caption for Figure 7 for details.

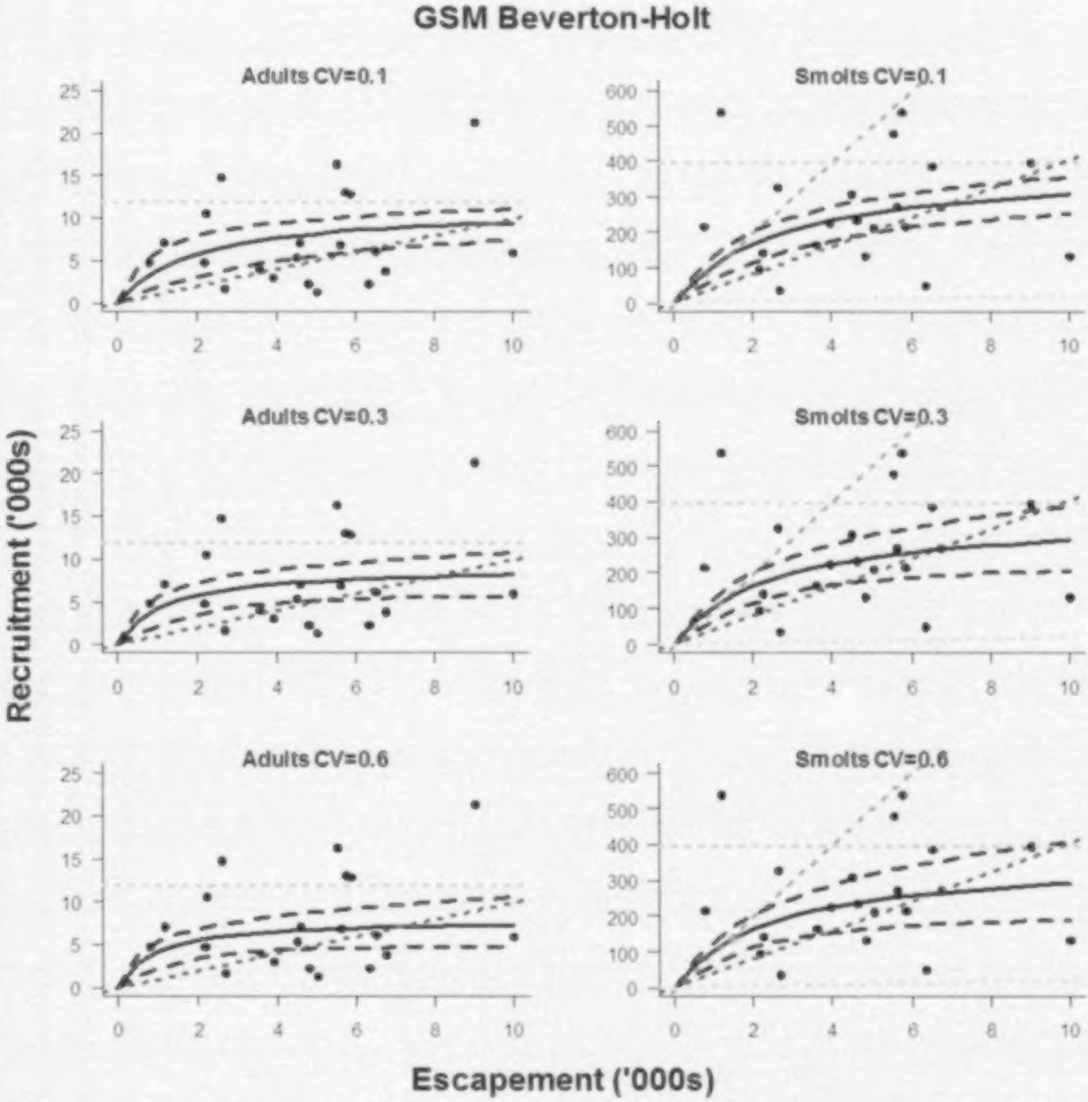


Figure 9. Stock-recruitment relationships for the Georgia Strait Mainland (GSM) Coho Salmon CU based on a Beverton-Holt model fit to spawner-adult recruit (left column) and spawner-smolt recruit (right column) data sets. See caption for Figure 7 for details.

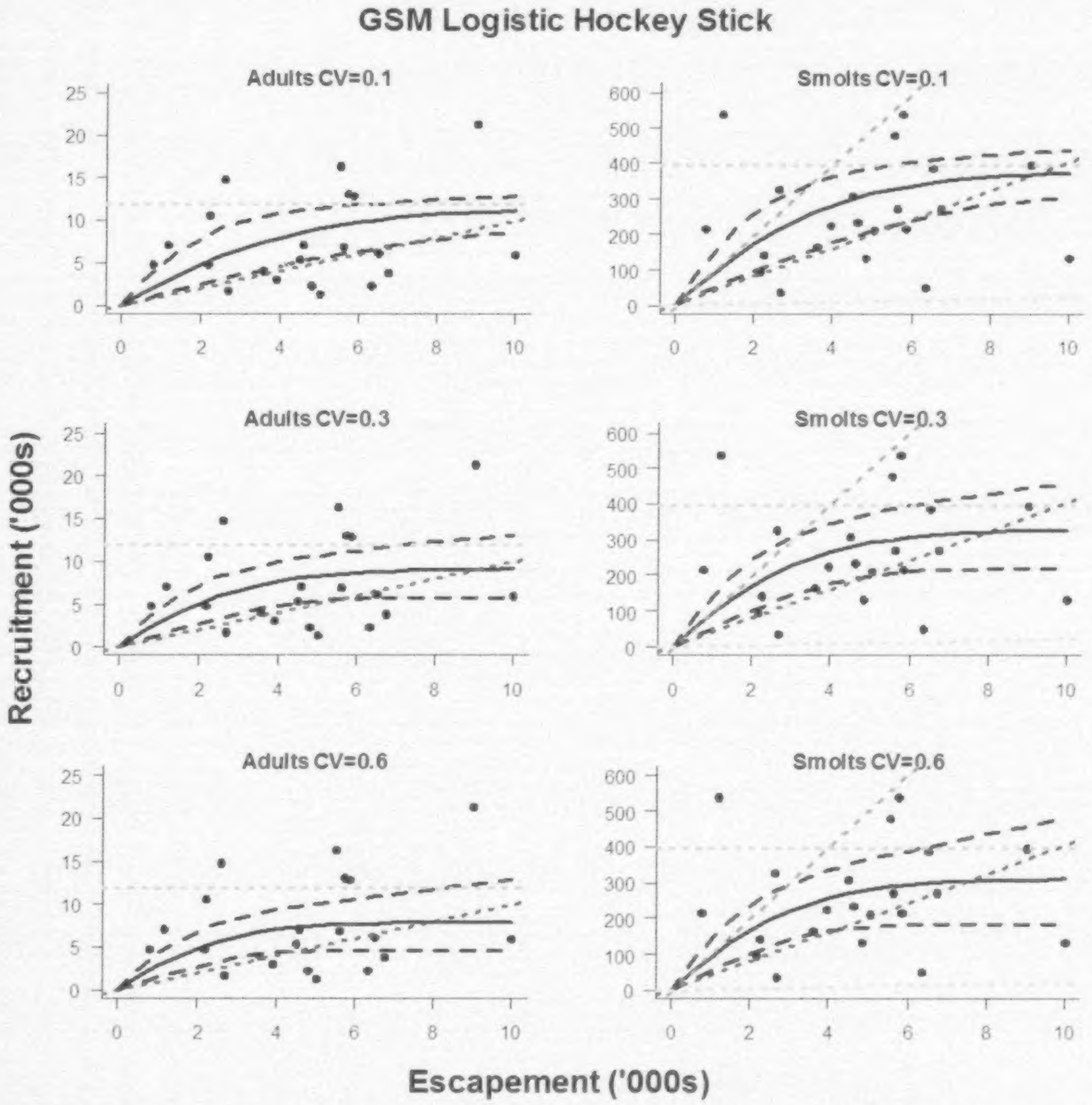


Figure 10. Stock-recruitment relationships for the Georgia Strait Mainland (GSM) Coho Salmon CU based on a Logistic Hockey Stick model fit to spawner-adult recruit (left column) and spawner-smolt recruit (right column) data sets. See caption for Figure 7 for details.

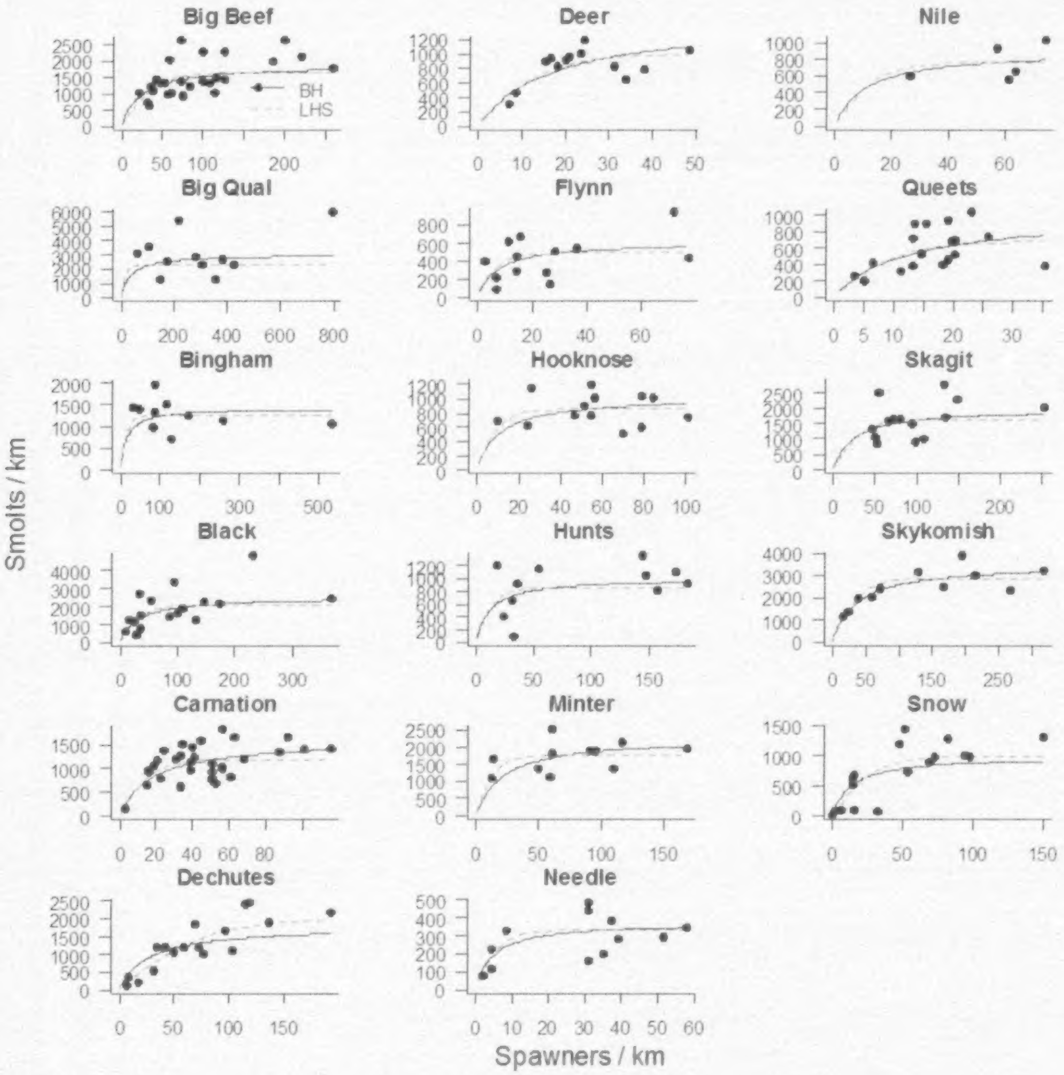


Figure 11. Comparison of fits of Beverton-Holt (BH, solid black line) and Logistic Hockey Stick (LHS, red dashed line) models to a regional spawner-smolt stock-recruit data set (1941 - 2004) (reproduced from results in Korman and Tompkins 2014). Note these models were fit using a hierarchical Bayesian approach.

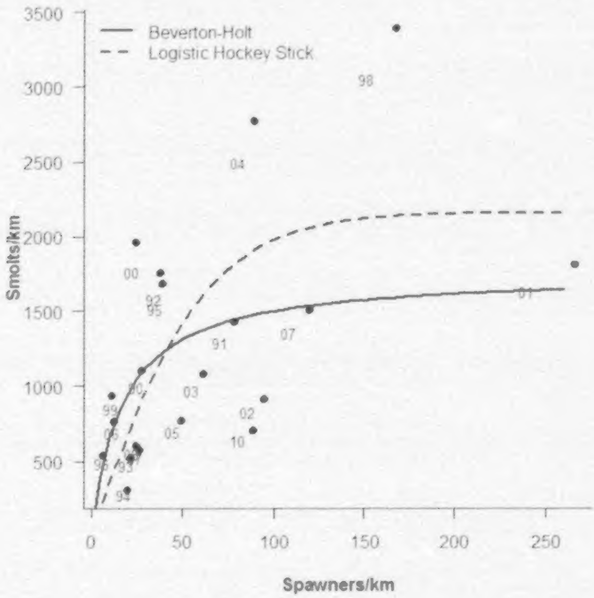


Figure 12. Spawner-smolt recruit data set for Black Creek, 1990-2010. Note that a different estimate of accessible stream length was used to generate this figure than the comparable one in Figure 11.

APPENDIX 1: ANNUAL COHO SALMON SMOLT DATA

Table A1. Annual Coho Salmon smolt data and sources by brood year.

MU	CU	Stream Name	Brood Year	Smolts	Spawners	km	Smolts/km	Smolts/ Spawner	Spawners/ km	Smolt Data Source
GS-VI	EVI-GS	Black_Creek	1983	59,932	-	46	1,317	-	-	[5]Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Black_Creek	1984	38,212	-	46	840	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Black_Creek	1985	72,301	-	46	1,589	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Black_Creek	1986	76,404	-	46	1,679	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Black_Creek	1987	29,862	-	46	656	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Black_Creek	1988	118,902	-	46	2,613	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Black_Creek	1989	53,876	-	46	1,184	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Black_Creek	1990	50,271	1,237	46	1,105	41	27	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Black_Creek	1991	65,171	3,568	46	1,432	18	78	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Black_Creek	1992	79,906	1,720	46	1,756	46	38	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Black_Creek	1993	24,074	959	46	529	25	21	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Black_Creek	1994	14,178	900	46	312	16	20	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Black_Creek	1995	76,592	1,760	46	1,683	44	39	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Black_Creek	1996	24,738	284	46	544	87	6	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Black_Creek	1997	26,370	1,200	46	580	22	26	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Black_Creek	1998	154,326	7,616	46	3,392	20	167	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Black_Creek	1999	42,772	511	46	940	84	11	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Black_Creek	2000	89,400	1,114	46	1,965	80	24	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Black_Creek	2001	82,323	12,100	46	1,809	7	266	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Black_Creek	2002	41,790	4,322	46	918	10	95	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Black_Creek	2003	49,133	2,780	46	1,080	18	61	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Black_Creek	2004	126,171	4,065	46	2,773	31	89	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Black_Creek	2005	35,265	2,248	46	775	16	49	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Black_Creek	2006	34,700	565	46	763	61	12	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Black_Creek	2007	68,517	5,453	46	1,506	13	120	Steve Baillie, DFO pers comm

---

[5] Steve Baillie, DFO, South Coast Area, Stock Assessment, Nanaimo, BC

MU	CU	Stream Name	Brood Year	Smolts	Spawners	km	Smolts/km	Smolts/ Spawner	Spawners/ km	Smolt Data Source
GS-VI	EVI-GS	Black_Creek	2008	27,750	1,120	46	610	25	25	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Black_Creek	2010	32,274	4,050	46	709	8	89	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Bush	1998	1,593	-	2	937	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Bush	2003	4,521	-	2	2,659	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Bush	2004	4,839	-	2	2,846	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Bush	2005	326	-	2	192	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Bush	2006	1,015	-	2	597	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Bush	2007	1,021	-	2	601	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Cowichan*	1995	203,218	-	391	520	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Cowichan*	1997	184,061	-	391	471	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Cowichan*	1998	530,346	-	391	1,356	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Cowichan*	1999	484,590	-	391	1,239	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Cowichan*	2000	490,830	-	391	1,255	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Cowichan*	2001	230,856	-	391	590	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Cowichan*	2003	262,053	-	391	670	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Cowichan*	2004	187,181	-	391	479	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Cowichan*	2005	30,157	-	391	77	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Englishman	1996	33,531	-	59	567	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Englishman	1997	50,622	-	59	856	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Englishman	1999	31,005	2,978	59	524	10	50	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Englishman	2000	38,996	5,280	59	659	7	89	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Englishman	2001	39,100	8,000	59	661	5	135	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Englishman	2002	38,000	3,100	59	643	12	52	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Englishman	2003	42,701	3,200	59	722	13	54	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Englishman	2007	85,467	1,165	59	1,445	73	20	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Englishman	2008	42,038	2,741	59	711	15	46	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Kirby	1996	9,087	-	2	3,786	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Kirby	1997	4,169	-	2	1,737	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Kirby	1998	4,988	-	2	2,078	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Kirby	1999	5,689	-	2	2,370	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Kirby	2000	7,697	-	2	3,207	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Little	1998	15,509	1,000	17	908	16	59	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Little	1999	6,973	-	17	408	-	-	Steve Baillie, DFO pers comm

MU	CU	Stream Name	Brood Year	Smolts	Spawners	km	Smolts/km	Smolts/ Spawner	Spawners/ km	Smolt Data Source
GS-VI	EVI-GS	Little	2000	16,959	350	17	993	48	20	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Little	2001	18,986	2,000	17	,112	9	117	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Little	2002	15,379	-	17	900	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Little	2003	13,407	-	17	785	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Little	2004	6,350	-	17	372	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Little	2005	5,796	-	17	339	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Little	2006	8,828	-	17	517	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Little	2007	19,214	-	17	1,125	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Little	2008	6,888	-	17	403	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Little	2009	600	-	17	35	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Little	2010	18,083	-	17	1,059	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Millard	1997	5,098	-	4	1,217	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Millard	1998	15,808	179	4	3,773	88	43	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Millard	1999	10,081	85	4	2,406	119	20	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Millard	2000	2,988	55	4	713	54	13	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Millard	2001	5,214	131	4	1,244	40	31	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Millard	2002	4,760	73	4	1,136	17	65	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Millard	2003	645	35	4	154	18	8	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Millard	2004	2,402	96	4	573	25	23	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Millard	2005	336	-	4	80	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Millard	2006	2,274	-	4	543	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Millard	2007	840	-	4	200	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Millard	2008	1,756	-	4	419	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Millard	2010	825	-	4	197	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Millard	2011	751	-	4	179	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Millstone	1998	5,949	-	31	191	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Millstone	2000	1,403	-	31	45	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Millstone	2002	7,580	-	31	243	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Millstone	2003	6,956	-	31	223	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Millstone	2004	15,007	-	31	481	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Millstone	2007	17,181	-	31	551	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Morrison	1999	1,696	-	9	187	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Morrison	2000	14,585	-	9	1,610	-	-	Steve Baillie, DFO pers comm

MU	CU	Stream Name	Brood Year	Smolts	Spawners	km	Smolts/km	Smolts/ Spawner	Spawners/ km	Smolt Data Source
GS-VI	EVI-GS	Morrison	2001	9,996	-	9	1,103	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Morrison	2002	4,734	-	9	523	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Morrison	2003	6,698	-	9	739	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Morrison	2004	3,789	-	9	418	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Morrison	2005	5,174	-	9	571	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Morrison	2006	6,018	-	9	664	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Morrison	2007	11,264	-	9	1,243	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Quinsam	1978	61,304	-	94	649	-	-	Dave Ewart, DFO pers comm[6]
GS-VI	EVI-GS	Quinsam	1979	59,242	-	94	627	-	-	Dave Ewart, DFO pers comm
GS-VI	EVI-GS	Quinsam	1980	27,304	-	94	289	-	-	Dave Ewart, DFO pers comm
GS-VI	EVI-GS	Quinsam	1981	50,417	-	94	534	-	-	Dave Ewart, DFO pers comm
GS-VI	EVI-GS	Quinsam	1982	62,249	-	94	659	-	-	Dave Ewart, DFO pers comm
GS-VI	EVI-GS	Quinsam	1983	55,746	-	94	590	-	-	Dave Ewart, DFO pers comm
GS-VI	EVI-GS	Quinsam	1984	44,634	-	94	473	-	-	Dave Ewart, DFO pers comm
GS-VI	EVI-GS	Quinsam	1985	49,764	-	94	527	-	-	Dave Ewart, DFO pers comm
GS-VI	EVI-GS	Quinsam	1986	76,839	-	94	814	-	-	Dave Ewart, DFO pers comm
GS-VI	EVI-GS	Quinsam	1987	29,304	-	94	310	-	-	Dave Ewart, DFO pers comm
GS-VI	EVI-GS	Quinsam	1988	86,431	-	94	915	-	-	Dave Ewart, DFO pers comm
GS-VI	EVI-GS	Quinsam	1989	35,900	-	94	380	-	-	Dave Ewart, DFO pers comm
GS-VI	EVI-GS	Quinsam	1990	57,998	-	94	614	-	-	Dave Ewart, DFO pers comm
GS-VI	EVI-GS	Quinsam	1994	71,589	-	94	758	-	-	Dave Ewart, DFO pers comm
GS-VI	EVI-GS	Quinsam	1995	156,116	-	94	1,653	-	-	Dave Ewart, DFO pers comm
GS-VI	EVI-GS	Quinsam	1996	59,626	-	94	631	-	-	Dave Ewart, DFO pers comm
GS-VI	EVI-GS	Quinsam	1997	67,783	16,174	94	718	4	171	Dave Ewart, DFO pers comm
GS-VI	EVI-GS	Quinsam	1998	125,118	21,411	94	1,325	6	227	Dave Ewart, DFO pers comm
GS-VI	EVI-GS	Quinsam	1999	82,388	10,108	94	872	8	107	Dave Ewart, DFO pers comm
GS-VI	EVI-GS	Quinsam	2000	32,874	20,289	94	348	2	215	Dave Ewart, DFO pers comm
GS-VI	EVI-GS	Quinsam	2001	42,325	23,578	94	448	2	250	Dave Ewart, DFO pers comm
GS-VI	EVI-GS	Quinsam	2002	30,677	15,683	94	325	2	166	Dave Ewart, DFO pers comm
GS-VI	EVI-GS	Quinsam	2004	29,252	15,318	94	310	2	162	Dave Ewart, DFO pers comm

---

[6] Dave Ewart, DFO Retired, Campbell River, BC.

MU	CU	Stream Name	Brood Year	Smolts	Spawners	km	Smolts/km	Smolts/ Spawner	Spawners/ km	Smolt Data Source
GS-VI	EVI-GS	Quinsam	2007	40,651	4,296	94	430	9	45	Dave Ewart, DFO pers comm
GS-VI	EVI-GS	Quinsam	2008	26,151	4,167	94	277	6	44	Dave Ewart, DFO pers comm
GS-VI	EVI-GS	Quinsam	2010	65,999	4,948	94	699	13	52	Dave Ewart, DFO pers comm
GS-VI	EVI-GS	Quinsam	2011	25,383	6,573	94	269	4	70	Dave Ewart, DFO pers comm
GS-VI	EVI-GS	Simms	2001	10,803	313	14	798	35	23	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Simms	2002	2,575	101	14	190	25	7	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Simms	2003	2,731	30	14	427	193	2	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Simms	2004	8,682	-	14	642	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Tsolum	2003	31,197	-	92	338	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Tsolum	2004	14,217	600	92	154	-	6	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Tsolum	2005	25,608	-	92	277	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Tsolum	2006	38,024	-	92	412	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Tsolum	2007	96,243	-	92	1,042	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Tsolum	2008	7,090	-	92	77	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Tsolum	2009	10,280	-	92	111	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Waterloo	2000	2,435	147	2	1,368	17	83	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Waterloo	2001	1,402	170	2	788	8	96	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Waterloo	2002	1,519	154	2	853	10	87	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Waterloo	2003	2,329	66	2	1,308	35	37	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Waterloo	2004	2,042	47	2	1,147	43	26	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Waterloo	2005	922	-	2	518	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Waterloo	2006	163	-	2	92	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Waterloo	2007	2,457	-	2	1,380	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Waterloo	2008	607	-	2	341	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Willow	1996	3,699	-	16	234	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Willow	1997	10,636	-	16	673	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Willow	1998	16,192	-	16	1,025	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Willow	1999	8,712	26	16	551	-	2	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Woods	1996	3,713	-	10	373	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Woods	1997	936	25	10	94	37	3	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Woods	1998	1,988	270	10	200	7	27	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Woods	1999	1,987	-	10	199	-	-	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Woods	2000	4,603	87	10	462	53	9	Steve Baillie, DFO pers comm

MU	CU	Stream Name	Brood Year	Smolts	Spawners	km	Smolts/km	Smolts/ Spawner	Spawners/ km	Smolt Data Source
GS-VI	EVI-GS	Woods	2001	1,307	89	10	131	15	9	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Woods	2002	232	35	10	23	7	4	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Woods	2003	196	29	10	20	7	3	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Woods	2004	459	80	10	46	6	8	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Woods	2005	148	22	10	15	7	2	Steve Baillie, DFO pers comm
GS-VI	EVI-GS	Woods	2006	284	12	10	29	24	1	Steve Baillie, DFO pers comm
GSM	GSM	Myrtle	1998	2,131	-	8	256	-	-	Steve Baillie, DFO pers comm
GSM	GSM	Myrtle	1999	1,800	-	8	217	-	-	Steve Baillie, DFO pers comm
GSM	GSM	Myrtle	2000	3,563	27	8	429	132	3	Steve Baillie, DFO pers comm
GSM	GSM	Myrtle	2001	1,723	57	8	207	30	7	Steve Baillie, DFO pers comm
GSM	GSM	Myrtle	2002	2,767	49	8	333	56	6	Steve Baillie, DFO pers comm
GSM	GSM	Myrtle	2003	2,046	49	8	246	42	6	Steve Baillie, DFO pers comm
GSM	GSM	Myrtle	2004	1,767	41	8	213	43	5	Steve Baillie, DFO pers comm
GSM	GSM	Myrtle	2005	544	14	8	65	39	2	Steve Baillie, DFO pers comm
GSM	GSM	Myrtle	2006	340	21	8	41	16	3	Steve Baillie, DFO pers comm
GSM	GSM	Myrtle	2007	630	-	8	76	-	-	Steve Baillie, DFO pers comm
GSM	GSM	Myrtle	2008	644	8	8	77	81	1	Steve Baillie, DFO pers comm
GSM	GSM	Myrtle	2009	708	13	8	85	54	2	Steve Baillie, DFO pers comm
GSM	GSM	Myrtle	2010	1,665	20	8	200	83	2	Steve Baillie, DFO pers comm
GSM	GSM	Whittall	1998	685	-	3	215	-	-	Steve Baillie, DFO pers comm
GSM	GSM	Whittall	1999	1,108	-	3	347	-	-	Steve Baillie, DFO pers comm
GSM	GSM	Whittall	2000	1,076	-	3	337	-	-	Steve Baillie, DFO pers comm
GSM	GSM	Whittall	2001	607	-	3	190	-	-	Steve Baillie, DFO pers comm
GSM	HS-BI	Cheakamus*	2001	97,633	-	37	2,625	-	-	BC Hydro Cheakamus Water Use Plan Year 6. Cheakamus River Juvenile Outmigrant Enumeration. Reference: CMSMON-1A
GSM	HS-BI	Cheakamus*	2002	131,841	-	37	3,544	-	-	
GSM	HS-BI	Cheakamus*	2003	154,774	-	37	4,161	-	-	
GSM	HS-BI	Cheakamus*	2004	93,630	-	37	2,517	-	-	
GSM	HS-BI	Cheakamus*	2005	80,520	-	37	2,165	-	-	
GSM	HS-BI	Cheakamus*	2007	128,146	-	37	3,445	-	-	
GSM	HS-BI	Cheakamus*	2008	106,916	-	37	2,874	-	-	
GSM	HS-BI	Cheakamus*	2009	123,951	-	37	3,332	-	-	
GSM	HS-BI	Cheakamus*	2010	132,651	-	37	3,566	-	-	
GSM	HS-BI	Cheakamus*	2011	106,564	-	37	2,865	-	-	

MU	CU	Stream Name	Brood Year	Smolts	Spawners	km	Smolts/km	Smolts/ Spawner	Spawners/ km	Smolt Data Source
GSM	HS-BI	Cheakamus*	2012	87,687	-	37	2,357	-	-	
GSM	HS-BI	Seymour*	2009	65,426	-	30	2,166	-	-	Metro Vancouver Seymour River Juvenile Salmonid Outmigration Monitoring, Spring 2012.
GSM	HS-BI	Seymour*	2010	114,270	-	30	3,784	-	-	
GSM	HS-BI	Seymour*	2011	63,653	-	30	2,108	-	-	
GSM	HS-BI	Seymour*	2012	73,704	-	30	2,441	-	-	
GSM	HS-BI	Seymour*	2013	38,522	-	30	1,276	-	-	
LFR	L.Fraser	Coquitlam*	2000	32,085	-	24	1,365	-	-	BC Hydro Coquitlam-Buntzen Water Use Plan Year 6. Lower Coquitlam River Fish Productivity Index. Reference: COQMON #7
LFR	L.Fraser	Coquitlam*	2002	18,226	-	24	776	-	-	
LFR	L.Fraser	Coquitlam*	2003	27,121	-	24	1,154	-	-	
LFR	L.Fraser	Coquitlam*	2004	25,778	-	24	1,097	-	-	
LFR	L.Fraser	Coquitlam*	2005	27,062	-	24	1,152	-	-	
LFR	L.Fraser	Coquitlam*	2006	27,203	-	24	1,158	-	-	
LFR	L.Fraser	Coquitlam*	2007	16,425	-	24	699	-	-	
LFR	L.Fraser	Coquitlam*	2008	28,964	-	24	1,233	-	-	
LFR	L.Fraser	Coquitlam*	2009	47,895	-	24	2,038	-	-	
LFR	L.Fraser	Coquitlam*	2010	26,812	-	24	1,141	-	-	
LFR	L.Fraser	Coquitlam*	2011	21,683	-	24	923	-	-	
LFR	L.Fraser	S. Alouette*	1998	32,400	-	45	718	-	-	BC Hydro Alouette Project Water Use Plan Year 5. Alouette River Smolt Enumeration. Reference # ALUMON-1
LFR	L.Fraser	S. Alouette*	1999	20,476	-	45	454	-	-	
LFR	L.Fraser	S. Alouette*	2000	40,006	-	45	886	-	-	
LFR	L.Fraser	S. Alouette*	2001	27,578	-	45	611	-	-	
LFR	L.Fraser	S. Alouette*	2003	38,716	-	45	857	-	-	
LFR	L.Fraser	S. Alouette*	2004	33,760	-	45	748	-	-	
LFR	L.Fraser	S. Alouette*	2005	26,040	-	45	577	-	-	
LFR	L.Fraser	S. Alouette*	2006	29,182	-	45	646	-	-	
LFR	L.Fraser	S. Alouette*	2007	6,080	-	45	135	-	-	
LFR	L.Fraser	S. Alouette*	2008	13,016	-	45	288	-	-	
LFR	L.Fraser	S. Alouette*	2009	80,312	-	45	1,779	-	-	
LFR	L.Fraser	S. Alouette*	2010	39,770	-	45	881	-	-	
LFR	L.Fraser	S. Alouette*	2011	38,480	-	45	852	-	-	
LFR	L.Fraser	S. Alouette*	2012	76,092	-	45	1,685	-	-	
LFR	L.Fraser	Salmon	1984	294,232	-	123	2,392	-	-	Steve Baillie, DFO pers comm
LFR	L.Fraser	Salmon	1985	160,290	-	123	1,303	-	-	Steve Baillie, DFO pers comm

MU	CU	Stream Name	Brood Year	Smolts	Spawners	km	Smolts/km	Smolts/ Spawner	Spawners/ km	Smolt Data Source
LFR	L.Fraser	Salmon	1986	238,888	-	123	1,942	-	-	Steve Baillie, DFO pers comm
LFR	L.Fraser	Salmon	1987	168,804	-	123	1,372	-	-	Steve Baillie, DFO pers comm
LFR	L.Fraser	Salmon	1988	212,923	-	123	1,731	-	-	Steve Baillie, DFO pers comm
LFR	L.Fraser	Salmon	1989	114,394	-	123	930	-	-	Steve Baillie, DFO pers comm
LFR	L.Fraser	Salmon	1990	153,846	-	123	1,251	-	-	Steve Baillie, DFO pers comm
LFR	L.Fraser	Salmon	1991	57,675	-	123	469	-	-	Steve Baillie, DFO pers comm
LFR	L.Fraser	Salmon	1992	122,000	-	123	992	-	-	Steve Baillie, DFO pers comm
LFR	L.Fraser	Salmon	1993	99,000	5,913	123	805	17	48	Steve Baillie, DFO pers comm
LFR	L.Fraser	Salmon	1994	121,000	-	123	984	-	-	Steve Baillie, DFO pers comm
LFR	L.Fraser	Salmon	1995	121,000	-	123	984	-	-	Steve Baillie, DFO pers comm
LFR	L.Fraser	Salmon	1996	59,800	2,639	123	486	23	21	Steve Baillie, DFO pers comm
LFR	L.Fraser	Salmon	1997	86,667	3,947	123	705	22	32	Steve Baillie, DFO pers comm
LFR	L.Fraser	Salmon	1998	83,374	2,860	123	678	29	23	Steve Baillie, DFO pers comm
LFR	L.Fraser	Salmon	1999	65,793	1,973	123	535	33	16	Steve Baillie, DFO pers comm
LFR	L.Fraser	Salmon	2000	141,557	5,067	123	1,151	28	41	Steve Baillie, DFO pers comm
LFR	L.Fraser	Salmon	2001	89,391	6,621	123	727	14	54	Steve Baillie, DFO pers comm
LFR	L.Fraser	Salmon	2002	65,597	5,274	123	533	12	43	Steve Baillie, DFO pers comm
LFR	L.Fraser	Salmon	2003	58,851	3,297	123	478	18	27	Steve Baillie, DFO pers comm
LFR	L.Fraser	Salmon	2005	38,587	-	123	314	-	-	Steve Baillie, DFO pers comm
LFR	L.Fraser	Salmon	2007	106,215	1,876	123	864	57	15	Steve Baillie, DFO pers comm

* Stream names marked with an asterisks (*) identify rivers where the smolt count did not occur at the mouth of the river. Refer to Section 2.1.5. for more information.

APPENDIX 2: COHO SALMON-BEARING SALMON STREAMS

Table A2. Watershed area, stream order and accessible length by gradient limit for all Coho Salmon-bearing salmon streams within the GSM, LFR, LILL, EVI-GS, HS-BI and BB CUs.

Watershed		Area (km^2)	Stream Order	Minimum Stream Order	Accessible Length (m)			
					<8% gradient	<6% gradient	<4% gradient	<2% gradient
Georgia Strait Mainland		*minimum stream order:*		*1*				
1	ANDERSON CREEK	17.9	3	1	3,580	3,580	3,250	2,830
2	ANGUS CREEK	8.6	3	1	1,020	1,020	910	600
3	BIRD COVE CREEK	2.2	1	1	1,440	1,380	1,310	1,310
4	BLACK LAKE CREEK	10.4	2	1	3,430	3,370	3,370	3,370
5	BREM RIVER	233.4	5	1	2,000	1,640	1,420	1,220
6	BREM RIVER TRIBUTARY	10.7	3	1	270	160	60	-
7	BRITTAIN RIVER	122.9	5	1	6,730	6,290	6,190	5,600
8	BURNET CREEK	9.3	3	1	540	420	180	70
9	CARLSON CREEK	27.7	3	1	340	340	150	150
10	CARRINGTON COVE CREEK	2.1	1	1	320	260	210	210
11	CRANBY CREEK	18.6	3	1	1,990	1,930	1,620	1,520
12	DEIGHTON CREEK	8.5	2	1	2,220	2,110	1,530	1,240
13	DESERTED RIVER	112.6	5	1	8,570	8,110	7,390	6,940
14	DORISTON CREEK	6.9	2	1	1,140	1,090	1,020	610
15	FORBES CREEK	51.0	4	1	1,890	1,580	1,040	990
16	GRAY CREEK	59.0	5	1	1,310	1,310	1,240	870
17	HUNAECHIN CREEK	155.9	5	1	2,260	2,200	1,940	1,540
18	JEFFERD CREEK	4.6	1	1	380	260	200	130
19	KELLY CREEK	9.8	1	1	1,220	1,220	800	310
20	KLITE RIVER	128.4	5	1	9,360	8,570	6,730	5,810
21	LANG CREEK	131.4	4	1	7,060	7,000	6,070	5,720
22	LITTLE TOBA RIVER	306.5	5	1	33,520	32,740	30,050	25,100
23	LOIS RIVER	470.8	6	1	360	260	150	00
24	MIXAL LAKE CREEK	8.4	2	1	2,040	1,980	1,860	1,860
25	MOUAT CREEK	34.1	3	1	1,130	1,070	940	580
26	MYERS CREEK	21.1	4	1	3,980	3,920	3,640	3,470

Watershed		Area (km^2)	Stream Order	Minimum Stream Order	Accessible Length (m)			
					<8% gradient	<6% gradient	<4% gradient	<2% gradient
Georgia Strait Mainland		*minimum stream order:*		*1*				
27	MYRTLE CREEK	19.0	2	1	8,130	7,840	7,530	6,840
28	OKEOVER CREEK	18.0	2	1	5,910	5,540	4,210	3,290
29	PENDRELL SOUND CREEK	3.4	3	1	2,140	2,070	1,750	1,680
30	QUARRY LAKE CREEK	7.8	2	1	3,210	2,930	2,770	2,600
31	QUATAM RIVER	157.3	5	1	15,160	14,780	14,090	9,990
32	REFUGE COVE CREEK	1.6	2	1	1,380	1,380	1,380	1,380
33	RUBY CREEK	60.7	3	1	21,390	21,230	20,510	20,340
34	SECHELT CREEK	84.1	5	1	880	830	830	540
35	SKWAWKA RIVER	201.6	6	1	7,410	7,380	6,850	6,460
36	SLIAMMON CREEK	58.4	5	1	2,420	2,360	2,080	1,740
37	SNAKE BAY CREEK	4.2	2	1	590	410	360	110
38	STORE CREEK	3.4	1	1	100	50	-	-
39	TAHUMMING RIVER	255.1	5	1	530	530	330	330
40	THEODOSIA RIVER	133.7	5	1	9,310	9,130	8,600	8,090
41	TOBA RIVER	1313.2	6	1	170,220	167,550	164,420	159,130
42	TSUAHDI CREEK	23.1	3	1	670	670	670	670
43	TZOONIE RIVER	168.0	6	1	2,490	2,380	2,110	2,000
44	VANCOUVER RIVER	164.1	5	1	3,020	3,020	2,890	2,220
45	WAKEFIELD CREEK	11.8	2	1	400	340	50	-
46	WEST CREEK	17.9	2	1	6,850	6,790	6,790	6,740
47	WHITEROCK PASS CREEK	7.7	2	1	3,190	3,190	2,910	2,780
48	WHITTALL CREEK	10.0	2	1	3,130	2,960	2,060	1,120
				Subtotal	366,630	357,170	336,460	310,200

Watershed		Area (km^2)	Stream Order	Minimum Stream Order	Accessible Length (m)			
					<8%gradient	<6% gradient	<4% gradient	<2% gradient
Lower Fraser		*minimum stream order:*		*1*				
1	ALOUETTE RIVER	262.0	5	1	55,260	54,390	51,020	47,440
2	ATCHELITZ CREEK	10.0	3	1	13,500	13,500	13,500	13,430
3	BARNES CREEK	4.5	2	1	240	60	60	60

	Watershed	Area (km^2)	Stream Order	Minimum Stream Order	Accessible Length (m)			
					<8%gradient	<6% gradient	<4% gradient	<2% gradient
Lower Fraser		*minimum*	*stream order:*	*1*				
4	BELCHARTON CREEK	7.3	2	1	4,810	4,340	2,880	2,280
5	BIG SILVER CREEK	495.9	6	1	17,350	16,900	16,230	14,660
6	BLANEY CREEK	26.8	3	1	19,620	19,150	17,240	16,600
7	BOOTH CREEK	2.1	1	1	420	420	420	420
8	BORDEN CREEK	17.9	5	1	510	370	240	-
9	BOUCHIER CREEK	1.9	2	1	3,030	3,030	3,030	3,030
10	BRIDAL CREEK	12.4	4	1	160	160	160	160
11	BRUNETTE RIVER	67.6	3	1	24,960	24,390	23,680	1,950
12	BYRNE CREEK	7.5	1	1	4,280	3,990	3,390	2,880
13	CALKINS CREEK	3.6	2	1	4,000	4,000	4,000	4,000
14	CENTRE CREEK	39.0	4	1	730	610	310	130
15	CHEHALIS RIVER	397.2	5	1	22,130	22,010	21,610	18,220
16	CHILLIWACK CREEK	71.2	4	1	1,560	1,560	1,560	1,560
17	CHILLIWACK RIVER - UPPER	9.1	4	1	3,360	3,090	2,990	2,990
18	CHILLIWACK/VEDDER RIVER	371.7	6	1	151,310	148,420	143,200	132,050
19	CHILQUA CREEK	14.5	3	1	9,590	9,590	9,190	9,140
20	CLAYBURN CREEK	68.9	4	1	55,180	54,960	54,450	53,380
21	COGBURN CREEK	202.9	5	1	3,130	3,130	2,930	1,970
22	COGHLAN CREEK	13.6	3	1	16,140	15,890	14,220	12,910
23	COMO CREEK	6.8	2	1	3,370	3,310	3,240	3,170
24	COQUITLAM RIVER	223.1	5	1	23,540	23,310	22,790	21,510
25	DEPOT CREEK	24.0	4	1	2,050	1,910	1,460	1,180
26	DOWNES CREEK	6.4	2	1	2,980	2,920	2,420	2,200
27	DRAPER CREEK	7.1	2	1	1,330	1,280	960	730
28	DUNVILLE CREEK	10.4	3	1	2,740	2,740	2,740	2,740
29	EAST CREEK	3.6	3	1	160	160	160	110
30	ELK BROOK	6.7	2	1	7,020	7,020	7,020	7,020
31	FIFTEEN MILE CREEK	1.7	2	1	380	310	120	-
32	FOLEY CREEK	78.7	5	1	4,110	3,950	2,860	1,990
33	HARRISON RIVER	108.2	7	1	86,680	86,220	84,670	83,540

Watershed		Area (km^2)	Stream Order	Minimum Stream Order	Accessible Length (m)			
					<8%gradient	<6% gradient	<4% gradient	<2% gradient
Lower Fraser		*minimum stream order:*		*1*				
34	HICKS CREEK	11.4	3	1	4,180	4,070	3,830	3,720
35	HOPE SLOUGH	46.2	4	1	32,390	32,130	31,680	31,370
36	HOY CREEK	7.1	2	1	2,880	2,880	2,760	2,360
37	HYDE CREEK	8.4	2	1	6,730	6,130	4,930	3,070
38	INCHES CREEK	0.7	1	1	1,570	1,570	1,570	1,570
39	KANAKA CREEK	62.3	4	1	18,120	17,420	15,250	14,060
40	LAGACE CREEK	17.4	4	1	11,410	10,770	9,900	7,550
41	LITTLE TAMIHI CREEK	5.2	1	1	120	-	-	-
42	LIUMCHEN CREEK	40.1	4	1	370	370	370	370
43	LORENZETTA CREEK	15.0	2	1	3,140	3,050	2,860	2,810
44	LUCKAKUCK CREEK	7.8	1	1	2,900	2,900	2,900	2,900
45	MACINTYRE CREEK	7.0	3	1	2,740	2,430	2,310	2,100
46	MAHOOD CREEK	28.2	4	1	200	130	130	130
47	MARIA SLOUGH	28.0	3	1	32,920	32,770	32,600	32,350
48	MARSHALL CREEK	38.0	3	1	23,070	22,880	22,390	22,000
49	MCLENNAN CREEK	31.5	4	1	19,800	19,560	19,240	18,700
50	MIAMI CREEK	19.7	3	1	15,530	15,390	15,320	15,270
51	MOUNTAIN SLOUGH	31.9	3	1	25,270	25,090	24,900	24,690
52	MUSQUEAM CREEK	0.3	1	1	210	210	210	210
53	MYSTERY CREEK	25.0	3	1	260	190	70	70
54	NATHAN CREEK	33.4	4	1	20,620	20,020	18,450	16,950
55	NESAKWATCH CREEK	44.2	4	1	2,230	2,020	1,710	900
56	NEVIN CREEK	8.1	2	1	2,280	2,120	1,990	1,920
57	NICOMEN SLOUGH	52.9	5	1	57,090	56,920	56,460	55,420
58	NORRISH CREEK	117.6	5	1	5,380	5,380	5,180	5,110
59	NORTH ALOUETTE RIVER	42.2	4	1	22,370	22,250	21,560	20,670
60	OR CREEK	21.3	4	1	1,630	1,280	670	330
61	PALEFACE CREEK	37.5	4	1	740	700	400	240
62	PARTINGTON CREEK	7.5	3	1	4,680	4,560	4,370	3,930
63	PITT RIVER	783.2	6	1	126,330	124,900	120,330	108,910
64	POST CREEK	24.5	3	1	2,310	2,190	1,580	1,020

Watershed		Area (km^2)	Stream Order	Minimum Stream Order	Accessible Length (m)			
					<8%gradient	<6% gradient	<4% gradient	<2% gradient
Lower Fraser		*minimum stream order:*		*1*				
65	PYE CREEK	2.6	1	1	380	380	270	220
66	RANGER CREEK	5.4	3	1	400	270	130	-
67	RYDER CREEK	7.7	3	1	930	900	900	900
68	SAKWI CREEK	17.6	4	1	610	610	470	230
69	SALMON RIVER	63.3	4	1	107,060	106,140	98,920	91,800
70	SALWEIN CREEK	0.5	1	1	590	590	590	590
71	SCOREY CREEK	1.5	2	1	240	240	180	120
72	SCOTT CREEK	10.9	3	1	4,050	3,990	3,930	3,850
73	SIDDALL CREEK	6.7	3	1	2,310	2,240	2,060	1,720
74	SILVERDALE CREEK	25.5	3	1	4,050	4,050	3,810	3,570
75	SLESSE CREEK	59.2	5	1	11,080	10,890	10,420	6,710
76	SOUTH ALOUETTE RIVER	254.3	5	1	45,150	44,280	40,910	37,330
77	SQUAWKUM CREEK	6.7	3	1	2,910	2,910	2,850	2,480
78	STAVE RIVER	1013.3	6	1	10,960	10,900	10,900	10,830
79	STEELHEAD CREEK	7.3	3	1	700	650	580	490
80	STONEY CREEK	6.6	1	1	570	570	570	300
81	STREET CREEK	3.1	2	1	5,120	5,120	5,120	5,120
82	SUMAS RIVER	64.3	6	1	76,560	76,490	76,230	75,600
83	SWELTZER RIVER	67.4	4	1	25,310	24,670	22,220	20,620
84	TAMIHI CREEK	47.5	5	1	920	920	370	210
85	TIPELLA CREEK	62.9	4	1	1,030	970	970	790
86	TROUT LAKE CREEK	22.2	4	1	500	440	380	200
87	TWENTY MILE CREEK	19.7	3	1	1,440	1,440	1,440	1,180
88	WAHLEACH CREEK	115.2	5	1	1,840	1,670	1,570	1,300
89	WEAVER CREEK	16.1	5	1	4,440	4,320	4,000	3,270
90	WEST CREEK	17.9	2	1	16,530	16,530	15,840	15,050
91	WHONNOCK CREEK	20.6	2	1	2,710	2,390	1,660	1,290
92	WIDGEON CREEK	75.7	5	1	29,250	28,780	27,350	25,950
93	YORKSON CREEK	15.5	4	1	17,340	17,340	14,850	13,470
				Subtotal	1,370,100	1,350,060	1,290,160	1,209,340

Table A2. (Continued)

	Watershed	Area (km^2)	Stream Order	Minimum Stream Order	Accessible Length (m)			
					<8%gradient	<6% gradient	<4% gradient	<2% gradient
Lillooet		*minimum stream order*		1				
1	BIRKENHEAD RIVER	642.2	6	1	104,450	101,620	94,210	83,890
2	CHIEF PAUL CREEK	23.0	3	1	60	60	-	-
3	DOUGLAS CREEK	104.0	5	1	860	860	800	730
4	GOWAN CREEK	95.2	5	1	2,170	2,100	1,730	740
5	GREEN RIVER	874.8	6	1	20,330	20,180	19,740	18,490
6	JOHN SANDY CREEK	4.4	4	1	1,060	1,060	1,000	900
7	KAKILA CREEK	82.4	1	1	970	810	540	480
8	LILLOOET RIVER - LOWER	1661.8	7	1	189,600	185,730	181,300	174,000
9	LILLOOET RIVER - UPPER	1574.2	7	1	311,320	306,080	295,310	275,340
10	MCKENZIE CREEK	10.2	3	1	3,840	3,790	3,660	3,620
11	MILLER CREEK	75.6	4	1	4,860	4,800	4,730	4,490
12	PEMBERTON CREEK	33.6	4	1	6,320	6,250	6,080	5,910
13	POOLE CREEK	42.3	5	1	8,730	8,080	6,910	5,690
14	RAILROAD CREEK	26.7	4	1	470	410	290	240
15	RYAN RIVER	416.0	5	1	29,110	28,800	28,530	28,210
16	SALMON CREEK	22.0	3	1	13,780	13,780	13,590	13,340
17	SAMPSON CREEK	29.8	4	1	1,260	1,260	1,210	1,150
18	SLOQUET CREEK	199.2	5	1	19,260	18,160	17,030	15,190
19	SNOWCAP CREEK	199.4	5	1	2,600	2,540	2,310	880
				Subtotal	721,050	706,370	678,970	633,290

	Watershed	Area (km^2)	Stream Order	Minimum Stream Order	Accessible Length (m)			
					<8% gradient	<6% gradient	<4% gradient	<2% gradient
Georgia Strait - East Vancouver Island		*minimum stream order:*		1				
1	ANNIE CREEK	9.5	1	1	690	690	690	520
2	AYUM CREEK	14.1	3	1	630	570	440	380
3	BEACH CREEK	3.9	1	1	1,190	1,130	880	500

					Accessible Length (m)			
Watershed		Area (km^2)	Stream Order	Minimum Stream Order	<8% gradient	<6% gradient	<4% gradient	<2% gradient
Georgia Strait - East Vancouver Island		*minimum stream order:*		*1*				
4	BECK CREEK	18.0	2	1	5,910	5,910	5,840	5,840
5	BLACK CREEK	64.6	4	1	45,570	45,570	45,420	44,290
6	BLOODS CREEK	2.2	1	1	210	160	160	110
7	BONELL CREEK	51.2	4	1	2,820	2,650	2,530	2,370
8	BONSALL CREEK	24.4	3	1	13,370	13,260	13,000	12,680
9	BROOKLYN CREEK	5.4	1	1	4,420	4,420	4,300	3,970
10	BUSH CREEK	28.2	2	1	1,740	1,740	1,740	1,680
11	CAMPBELL RIVER	72.2	7	1	10,250	10,250	10,250	10,150
12	CASEY CREEK	8.1	2	1	3,540	3,420	3,180	2,430
13	CHARTERS RIVER	19.4	4	1	700	700	510	420
14	CHASE RIVER	29.3	3	1	4,330	4,330	4,180	3,730
15	CHEF CREEK	8.3	3	1	6,250	6,160	6,050	5,880
16	CHEMAINUS RIVER	355.7	5	1	18,400	18,330	18,220	17,200
17	CLEAR CREEK	71.6	4	1	27,310	26,970	26,910	26,300
18	COLQUITZ RIVER	47.6	3	1	17,330	17,090	16,700	16,100
19	COOK CREEK	19.0	4	1	2,140	2,140	2,140	2,090
20	COWICHAN RIVER	671.5	7	1	391,830	387,280	376,250	365,540
21	COWIE CREEK	23.3	3	1	1,540	1,540	1,410	1,190
22	CRAIG CREEK	12.0	2	1	4,280	4,220	3,770	3,530
23	CRAIGFLOWER CREEK	22.8	3	1	4,340	4,270	4,140	4,020
24	DE MAMIEL CREEK	32.9	4	1	25,590	24,980	22,640	18,980
25	DEPARTURE CREEK	4.0	1	1	540	540	400	280
26	DOVE CREEK	42.8	3	1	22,500	22,140	20,420	17,450
27	DREW CREEK	2.9	1	1	2,460	2,460	2,460	2,340
28	ENGLISHMAN RIVER	316.0	6	1	59,120	58,730	56,220	52,630
29	FRENCH CREEK	69.7	4	1	10,780	10,780	10,710	10,660
30	FULFORD CREEK	21.4	3	1	4,910	4,520	4,230	3,620
31	GLENORA CREEK	21.8	4	1	14,330	14,030	13,080	11,620
32	GOLDSTREAM RIVER	57.6	4	1	4,840	4,670	4,220	3,440
33	HART CREEK	28.4	3	1	1,530	1,530	1,530	1,530

	Watershed	Area (km^2)	Stream Order	Minimum Stream Order	Accessible Length (m)			
					<8% gradient	<6% gradient	<4% gradient	<2% gradient
Georgia Strait - East Vancouver Island		*minimum stream order:*	*1*					
34	HASLAM CREEK	125.8	4	1	33,630	33,240	32,190	29,850
35	HEADQUARTERS CREEK	29.1	3	1	5,540	5,540	5,480	5,130
36	HOLDEN CREEK	23.2	3	1	9,190	9,190	9,190	8,970
37	HOLLAND CREEK	30.7	3	1	620	510	400	330
38	JORDAN RIVER	161.9	5	1	1,370	1,300	1,230	1,160
39	KELVIN CREEK	35.7	4	1	8,100	7,850	7,630	7,170
40	KINGFISHER CREEK	2.8	1	1	540	540	490	440
41	KIRBY CREEK	24.5	4	1	2,410	2,340	1,820	1,550
42	KITTY COLEMAN CREEK	12.8	3	1	13,230	13,220	12,620	11,420
43	KNARSTON CREEK	8.2	1	1	800	800	690	630
44	KOKSILAH RIVER	247.5	6	1	29,840	29,330	28,190	26,650
45	LANNON CREEK	2.7	2	1	990	990	990	940
46	LITTLE GEORGE CREEK	17.3	2	1	3,640	3,620	3,430	3,280
47	LITTLE OYSTER RIVER	38.2	3	1	39,760	39,450	38,920	36,610
48	LITTLE QUALICUM RIVER	252.4	4	1	32,120	31,940	31,070	29,760
49	LITTLE RIVER	18.9	3	1	17,080	17,080	16,780	16,040
50	MCKERCHER CREEK	16.3	3	1	6,310	5,610	5,000	3,940
51	MCNAUGHTON CREEK	8.9	3	1	2,490	2,430	2,370	2,250
52	MENZIES CREEK	23.9	4	1	4,680	4,450	3,930	2,710
53	MESACHIE CREEK	6.6	3	1	5,660	5,480	5,000	4,740
54	MILL STREAM	29.2	3	1	380	380	320	270
55	MILLARD CREEK	7.1	2	1	4,190	4,190	3,930	3,750
56	MILLSTONE RIVER	100.2	4	1	31,260	30,640	29,340	27,740
57	MOHUN CREEK	129.8	5	1	11,650	11,000	10,550	9,260
58	MORRISON CREEK	11.1	3	1	9,060	8,860	8,340	6,920
59	MUIR CREEK	66.0	5	1	2,830	2,760	2,740	2,740
60	NANAIMO RIVER	638.4	7	1	123,980	120,930	111,940	103,990
61	NANOOSE CREEK	34.0	3	1	3,090	3,030	3,030	3,030
62	NAPOLEON CREEK	3.0	2	1	3,760	3,760	3,760	3,710
63	NILE CREEK	16.5	3	1	6,180	6,180	6,070	5,960

Watershed		Area (km^2)	Stream Order	Minimum Stream Order	Accessible Length (m)			
					<8% gradient	<6% gradient	<4% gradient	<2% gradient
Georgia Strait - East Vancouver Island		*minimum stream order:*		*1*				
64	NORRIE CREEK	6.7	2	1	2,670	2,490	2,140	1,800
65	NORTH NANAIMO RIVER	62.4	4	1	38,860	37,050	34,180	30,980
66	NUNNS CREEK	6.3	2	1	4,170	4,170	4,110	3,800
67	OLIVER CREEK	5.0	4	1	3,820	3,460	2,100	1,880
68	OPEN BAY CREEK	12.0	2	1	6,350	6,090	5,070	4,490
69	OYSTER RIVER	323.6	6	1	28,600	28,510	28,130	26,450
70	PATRICIA CREEK	5.5	2	1	4,260	4,190	3,790	3,690
71	PORTER CREEK	4.4	1	1	230	170	110	-
72	PORTUGUESE CREEK	37.0	3	1	35,170	35,020	34,570	33,050
73	PUNTLEDGE RIVER	587.7	6	1	138,330	135,380	130,070	119,320
74	QUALICUM RIVER	146.2	5	1	12,730	12,730	12,440	11,980
75	QUINSAM RIVER	289.5	5	1	94,360	92,820	88,830	83,850
76	REAY CREEK	3.2	2	1	1,340	1,270	1,270	1,270
77	RICHARDS CREEK	20.8	3	1	18,230	18,070	17,210	15,700
78	ROBERTSON RIVER	99.0	5	1	29,860	28,930	26,600	22,370
79	ROCKY CREEK	7.2	3	1	450	450	190	-
80	ROSEWALL CREEK	44.1	4	1	4,480	4,360	4,250	4,250
81	ROY CREEK	12.6	2	1	6,170	6,110	5,560	5,280
82	SANDHILL CREEK	11.9	2	1	9,920	9,690	8,950	8,030
83	SANDY CREEK	2.5	1	1	2,070	1,910	1,860	1,660
84	SHAW CREEK	75.6	5	1	4,400	4,320	3,600	3,540
85	SIMMS CREEK	16.3	3	1	13,460	13,130	12,370	10,850
86	SOOKE RIVER	282.2	5	1	9,930	9,680	9,350	9,230
87	STOCKING CREEK	9.8	2	1	430	260	-	-
88	STORIE CREEK	4.5	2	1	5,760	5,700	5,210	3,860
89	SUTTON CREEK	43.9	4	1	9,670	9,300	7,930	7,190
90	TOD CREEK	24.3	3	1	160	160	50	-
91	TRENT RIVER	82.0	4	1	9,890	9,890	9,540	9,140
92	TSABLE RIVER	54.7	5	1	6,530	6,470	6,470	6,470
93	TSOLUM RIVER	157.6	5	1	92,380	91,690	88,900	83,140

	Watershed	Area (km^2)	Stream Order	Minimum Stream Order	Accessible Length (m)			
					<8% gradient	<6% gradient	<4% gradient	<2% gradient
Georgia Strait - East Vancouver Island		*minimum stream order:*	*1*					
94	TUGWELL CREEK	20.1	4	1	2,270	2,270	1,920	1,810
95	TYEE CREEK	12.2	2	1	410	340	290	290
96	WALKER CREEK	10.1	2	1	2,320	2,230	2,230	2,050
97	WATERLOO CREEK	7.8	3	1	1,780	1,540	1,540	1,410
98	WEXFORD CREEK	5.9	2	1	970	910	910	910
99	WHITEHOUSE CREEK	11.6	2	1	2,290	2,240	2,000	1,900
100	WILDWOOD CREEK	8.8	3	1	100	100	100	60
101	WILFRED CREEK	26.3	4	1	4,140	4,080	3,700	3,330
102	WILLOW CREEK	25.6	3	1	15,830	15,700	14,970	13,630
103	WOODS CREEK	10.9	3	1	9,960	9,890	9,620	8,640
				Subtotal	1,764,520	1,736,590	1,664,190	1,561,710

	Watershed	Area (km^2)	Stream Order	Minimum Stream Order	Accessible Length (m)			
					<8% gradient	<6% gradient	<4% gradient	<2% gradient
Howe Sound - Burrard Inlet		*minimum stream order:*	*1*					
1	ASHLU CREEK	342.6	5	1	5,860	5,560	5,560	4,780
2	BISHOP CREEK	6.9	4	1	120	120	-	-
3	BROHM RIVER	29.5	4	1	2,070	2,000	1,930	1,460
4	BROTHERS CREEK	9.5	2	1	430	430	300	180
5	CAPILANO RIVER	206.9	6	1	7,850	7,720	7,260	6,850
6	CHAPMAN CREEK	69.2	5	1	4,010	4,010	3,890	3,450
7	CHASTER CREEK	10.7	3	1	1,990	1,860	940	310
8	CHEAKAMUS RIVER	1004.3	6	1	37,200	36,080	33,780	30,840
9	CHUK-CHUK CREEK	10.9	4	1	1,070	940	880	880
10	DAKOTA CREEK	33.5	5	1	850	640	500	250
11	DRYDEN CREEK	2.6	2	1	2,500	2,390	1,800	1,590
12	FRIES CREEK	20.1	4	1	280	220	50	-
13	HASTINGS CREEK	8.4	2	1	60	60	-	-
14	HOP RANCH CREEK	5.3	3	1	2,190	2,080	2,020	1,990
15	HUTCHINSON CREEK	4.7	2	1	370	170	170	170

Watershed		Area (km^2)	Stream Order	Minimum Stream Order	Accessible Length (m)			
					<8% gradient	<6% gradient	<4% gradient	<2% gradient
Howe Sound - Burrard Inlet		*minimum stream order:*		*1*				
16	INDIAN RIVER	192.8	5	1	20,170	19,370	18,210	16,330
17	JULY CREEK	10.1	3	1	560	500	500	420
18	LANGDALE CREEK	8.1	2	1	770	490	310	70
19	LOGGERS LANE CREEK	5.6	2	1	2,880	2,880	2,880	2,880
20	LYNN CREEK	50.8	5	1	6,590	6,410	5,780	4,900
21	MACKAY CREEK	7.0	3	1	3,350	2,970	2,340	1,830
22	MAMQUAM RIVER	337.2	6	1	10,590	10,590	10,550	10,300
23	MAPLEWOOD CREEK	4.4	2	1	230	170	-	-
24	MASHITER CREEK	41.5	4	1	660	660	610	610
25	MCCARTNEY CREEK	3.2	1	1	180	180	120	120
26	MCNAB CREEK	67.8	5	1	5,710	5,300	4,980	4,150
27	MCNAIR CREEK	20.3	5	1	730	560	330	-
28	MEIGHAN CREEK	3.8	2	1	1,850	1,740	1,740	1,560
29	MILL CREEK	40.8	4	1	390	390	320	60
30	MOSQUITO CREEK	14.0	3	1	4,260	3,850	2,660	1,490
31	MOSSOM CREEK	5.0	3	1	580	390	220	110
32	NOONS CREEK	5.1	3	1	650	410	110	60
33	OUILLET CREEK	6.0	3	1	530	470	180	180
34	PILLCHUCK CREEK	27.5	3	1	6,880	6,820	6,720	6,550
35	POTLATCH CREEK	27.7	4	1	370	370	310	130
36	RAINY RIVER	68.5	5	1	2,910	2,750	2,310	1,330
37	ROBERTS CREEK	29.5	3	1	430	370	190	190
38	SEYMOUR RIVER	177.8	5	1	30,210	28,970	27,210	24,530
39	SHANNON CREEK	14.7	4	1	550	340	280	230
40	SHOVELNOSE CREEK	18.5	4	1	370	190	60	-
41	SOUTH TWIN CREEK	6.0	2	1	250	250	250	140
42	SPRING CREEK	25.6	3	1	190	190	120	120
43	SQUAMISH RIVER	1954.2	7	1	337,380	332,390	324,220	304,410
44	STAWAMUS RIVER	52.8	4	1	4,070	4,030	3,900	3,160
45	TERMINAL CREEK	9.2	3	1	5,970	5,660	4,990	4,330

Watershed		Area (km^2)	Stream Order	Minimum Stream Order	Accessible Length (m)			
					<8% gradient	<6% gradient	<4% gradient	<2% gradient
Howe Sound - Burrard Inlet		*minimum stream order:*		*1*				
46	WILSON CREEK	23.0	3	1	2,950	2,950	2,140	1,310
				Subtotal	520,060	506,890	483,620	444,250

Watershed		Area (km^2)	Stream Order	Minimum Stream Order	Accessible Length (m)			
					<8% gradient	<6% gradient	<4% gradient	<2% gradient
Boundary Bay		*minimum stream order*		*1*				
1	CAMPBELL RIVER	72.2	7	1	67,440	67,140	65,080	60,370
2	MURRAY CREEK	27.9	4	1	27,630	27,430	26,010	23,190
3	NICOMEKL RIVER	153.2	4	1	201,290	200,220	194,230	186,560
4	SERPENTINE RIVER	144.3	4	1	184,720	181,720	170,650	156,720
				Subtotal	481,080	476,510	455,970	426,840

APPENDIX 3: STREAM-SPECIFIC ESTIMATES OF SMOLTS/SPAWNERS

Table A3. Stream-specific estimates of average smolt yield and spawners required to produce estimated average smolts for each watershed in each CU. Note: The accessible stream length used here assumes a minimum stream order of 1 and a maximum gradient of 8%.

	Watershed	Area (km^2)	Stream Order	Accessible Stream Length (m)	Habitat-Based Estimates	
					Average Smolts	Spawners
Georgia Strait Mainland						
1	ANDERSON CREEK	18	3	3,580	3,111	94
2	ANGUS CREEK	9	3	1,020	785	24
3	BIRD COVE CREEK	2	1	1,440	1,146	35
4	BLACK LAKE CREEK	10	2	3,430	2,969	90
5	BREM RIVER	233	5	2,000	1,643	50
6	BREM RIVER TRIBUTARY	11	3	270	183	6
7	BRITTAIN RIVER	123	5	6,730	6,222	189
8	BURNET CREEK	9	3	540	391	12
9	CARLSON CREEK	28	3	340	236	7
10	CARRINGTON COVE CREEK	2	1	320	221	7
11	CRANBY CREEK	19	3	1,990	1,634	50
12	DEIGHTON CREEK	9	2	2,220	1,842	56
13	DESERTED RIVER	113	5	8,570	8,114	246
14	DORISTON CREEK	7	2	1,140	887	27
15	FORBES CREEK	51	4	1,890	1,544	47
16	GRAY CREEK	59	5	1,310	1,033	31
17	HUNAECHIN CREEK	156	5	2,260	1,878	57
18	JEFFERD CREEK	5	1	380	266	8
19	KELLY CREEK	10	1	1,220	955	29
20	KLITE RIVER	128	5	9,360	8,939	271
21	LANG CREEK	131	4	7,060	6,558	199
22	LITTLE TOBA RIVER	307	5	33,520	36,350	1,102
23	LOIS RIVER	471	6	360	251	8
24	MIXAL LAKE CREEK	8	2	2,040	1,679	51
25	MOUAT CREEK	34	3	1,130	879	27
26	MYERS CREEK	21	4	3,980	3,495	106
27	MYRTLE CREEK	19	2	8,130	1,530	26
28	OKEOVER CREEK	18	2	5,910	5,394	163

	Watershed	Area (km^2)	Stream Order	Accessible Stream Length (m)	Habitat-Based Estimates	
					Average Smolts	Spawners
Georgia Strait Mainland						
29	PENDRELL SOUND CREEK	3	3	2,140	1,769	54
30	QUARRY LAKE CREEK	8	2	3,210	2,760	84
31	QUATAM RIVER	157	5	15,160	15,187	460
32	REFUGE COVE CREEK	2	2	1,380	1,094	33
33	RUBY CREEK	61	3	21,390	22,175	672
34	SECHELT CREEK	84	5	880	668	20
35	SKWAWKA RIVER	202	6	7,410	6,916	210
36	SLIAMMON CREEK	58	5	2,420	2,025	61
37	SNAKE BAY CREEK	4	2	590	431	13
38	STORE CREEK	3	1	100	62	2
39	TAHUMMING RIVER	255	5	530	383	12
40	THEODOSIA RIVER	134	5	9,310	8,887	269
41	TOBA RIVER	1,313	6	170,220	217,727	6,598
42	TSUAHDI CREEK	23	3	670	496	15
43	TZOONIE RIVER	168	6	2,490	2,089	63
44	VANCOUVER RIVER	164	5	3,020	2,582	78
45	WAKEFIELD CREEK	12	2	400	282	9
46	WEST CREEK	18	2	6,850	6,344	192
47	WHITEROCK PASS CREEK	8	2	3,190	2,741	83
48	WHITTALL CREEK	10	2	3,130	853	26
			Subtotal	**366,630**	**395,603**	**11,968**
				Lower CL	**304,459**	**9,226**
				Upper CL	**486,746**	**14,750**

	Watershed	Area (km^2)	Stream Order	Accessible Stream Length (m)	Habitat-Based Estimates	
					Average Smolts	Spawners
Lower Fraser						
1	ALOUETTE RIVER	262	5	55,260	63,024	1,910
2	ATCHELITZ CREEK	10	3	13,500	13,369	405
3	BARNES CREEK	5	2	240	161	5
4	BELCHARTON CREEK	7	2	4,810	4,303	130
5	BIG SILVER CREEK	496	6	17,350	17,615	534

Watershed		Area (km^2)	Stream Order	Accessible Stream Length (m)	Habitat-Based Estimates	
					Average Smolts	Spawners
Lower Fraser						
6	BLANEY CREEK	27	3	19,620	20,166	611
7	BOOTH CREEK	2	1	420	297	9
8	BORDEN CREEK	18	5	510	368	11
9	BOUCHIER CREEK	2	2	3,030	2,591	79
10	BRIDAL CREEK	12	4	160	103	3
11	BRUNETTE RIVER	68	3	24,960	26,279	796
12	BYRNE CREEK	8	1	4,280	3,785	115
13	CALKINS CREEK	4	2	4,000	3,514	106
14	CENTRE CREEK	39	4	730	544	16
15	CHEHALIS RIVER	397	5	22,150	23,043	698
16	CHILLIWACK CREEK	71	4	1,560	1,251	38
17	CHILLIWACK RIVER - UPPER	9	4	3,360	2,902	88
18	CHILLIWACK/VEDDER RIVER	372	6	151,310	191,214	5,794
19	CHILQUA CREEK	15	3	9,590	9,181	278
20	CLAYBURN CREEK	69	4	55,180	62,923	1,907
21	COGBURN CREEK	203	5	3,130	2,685	81
22	COGHLAN CREEK	14	3	16,140	16,269	493
23	COMO CREEK	7	2	3,370	2,912	88
24	COQUITLAM RIVER	223	5	23,540	27,251	826
25	DEPOT CREEK	24	4	2,050	1,688	51
26	DOWNES CREEK	6	2	2,980	2,544	77
27	DRAPER CREEK	7	2	1,330	1,050	32
28	DUNVILLE CREEK	10	3	2,740	2,320	70
29	EAST CREEK	4	3	160	103	3
30	ELK BROOK	7	2	7,020	6,517	197
31	FIFTEEN MILE CREEK	2	2	380	266	8
32	FOLEY CREEK	79	5	4,110	3,620	110
33	HARRISON RIVER	108	7	86,680	103,479	3,136
34	HICKS CREEK	11	3	4,180	3,688	112
35	HOPE SLOUGH	46	4	32,390	35,004	1,061
36	HOY CREEK	7	2	2,880	2,451	74
37	HYDE CREEK	8	2	6,730	6,222	189

	Watershed	Area (km^2)	Stream Order	Accessible Stream Length (m)	Habitat-Based Estimates Average Smolts	Spawners
Lower Fraser						
38	INCHES CREEK	1	1	1,570	1,260	38
39	KANAKA CREEK	62	4	18,120	18,477	560
40	LAGACE CREEK	17	4	11,410	11,112	337
41	LITTLE TAMIHI CREEK	5	1	120	76	2
42	LIUMCHEN CREEK	40	4	370	259	8
43	LORENZETTA CREEK	15	2	3,140	2,694	82
44	LUCKAKUCK CREEK	8	1	2,900	2,469	75
45	MACINTYRE CREEK	7	3	2,740	2,320	70
46	MAHOOD CREEK	28	4	200	132	4
47	MARIA SLOUGH	28	3	32,920	35,635	1,080
48	MARSHALL CREEK	38	3	23,070	24,098	730
49	MCLENNAN CREEK	32	4	19,800	20,369	617
50	MIAMI CREEK	20	3	15,530	15,595	473
51	MOUNTAIN SLOUGH	32	3	25,270	26,638	807
52	MUSQUEAM CREEK	0.3	1	210	139	4
53	MYSTERY CREEK	25	3	260	176	5
54	NATHAN CREEK	33	4	20,620	21,299	645
55	NESAKWATCH CREEK	44	4	2,230	1,851	56
56	NEVIN CREEK	8	2	2,280	1,897	57
57	NICOMEN SLOUGH	53	5	57,090	65,326	1,980
58	NORRISH CREEK	118	5	5,380	4,866	147
59	NORTH ALOUETTE RIVER	42	4	22,370	23,295	706
60	OR CREEK	21	4	1,630	1,313	40
61	PALEFACE CREEK	38	4	740	553	17
62	PARTINGTON CREEK	7	3	4,680	4,175	127
63	PITT RIVER	783	6	126,330	156,723	4,749
64	POST CREEK	24	3	2,310	1,924	58
65	PYE CREEK	3	1	380	266	8
66	RANGER CREEK	5	3	400	282	9
67	RYDER CREEK	8	3	930	710	22
68	SAKWI CREEK	18	4	610	447	14
69	SALMON RIVER	63	4	107,060	105,235	4,209

	Watershed	Area (km^2)	Stream Order	Accessible Stream Length (m)	Habitat-Based Estimates	
					Average Smolts	Spawners
Lower Fraser						
70	SALWEIN CREEK	1	1	590	431	13
71	SCOREY CREEK	1	2	240	161	5
72	SCOTT CREEK	11	3	4,050	3,562	108
73	SIDDALL CREEK	7	3	2,310	1,924	58
74	SILVERDALE CREEK	25	3	4,050	3,562	108
75	SLESSE CREEK	59	5	11,080	10,760	326
76	SOUTH ALOUETTE RIVER	254	5	45,150	35,851	1,086
77	SQUAWKUM CREEK	7	3	2,910	2,479	75
78	STAVE RIVER	1,013	6	10,960	10,632	322
79	STEELHEAD CREEK	7	3	700	520	16
80	STONEY CREEK	7	1	570	415	13
81	STREET CREEK	3	2	5,120	4,608	140
82	SUMAS RIVER	64	6	76,560	90,251	2,735
83	SWELTZER RIVER	67	4	25,310	26,684	809
84	TAMIHI CREEK	48	5	920	701	21
85	TIPELLA CREEK	63	4	1,030	794	24
86	TROUT LAKE CREEK	22	4	500	360	11
87	TWENTY MILE CREEK	20	3	1,440	1,146	35
88	WAHLEACH CREEK	115	5	1,840	1,499	45
89	WEAVER CREEK	16	5	4,440	3,941	119
90	WEST CREEK	18	2	16,530	16,702	506
91	WHONNOCK CREEK	21	2	2,710	2,292	69
92	WIDGEON CREEK	76	5	29,250	31,289	948
93	YORKSON CREEK	16	4	17,340	17,604	533
			Subtotal	**1,370,100**	**1,484,479**	**46,005**
				Lower CL	**1,390,584**	**42,139**
				Upper CL	**1,578,373**	**47,829**

Table A3. (Continued)

Watershed		Area (km^2)	Stream Order	Accessible Stream Length (m)	Habitat-Based Estimates	
					Average Smolts	Spawners
Lillooet						
1	BIRKENHEAD RIVER	642	6	104,450	127,085	3,851
2	CHIEF PAUL CREEK	23	3	60	35	1
3	DOUGLAS CREEK	104	5	860	651	20
4	GOWAN CREEK	95	5	2,170	1,796	54
5	GREEN RIVER	875	6	20,330	20,970	635
6	JOHN SANDY CREEK	4	4	1,060	819	25
7	KAKILA CREEK	82	1	970	743	23
8	LILLOOET RIVER - LOWER	1,662	7	189,600	245,218	7,431
9	LILLOOET RIVER - UPPER	1,574	7	311,320	423,786	12,842
10	MCKENZIE CREEK	10	3	3,840	3,360	102
11	MILLER CREEK	76	4	4,860	4,352	132
12	PEMBERTON CREEK	34	4	6,320	5,807	176
13	POOLE CREEK	42	5	8,730	8,280	251
14	RAILROAD CREEK	27	4	470	336	10
15	RYAN RIVER	416	5	29,110	31,124	943
16	SALMON CREEK	22	3	13,780	13,674	414
17	SAMPSON CREEK	30	4	1,260	990	30
18	SLOQUET CREEK	199	5	19,260	19,759	599
19	SNOWCAP CREEK	199	5	2,600	2,190	66
Subtotal				**721,050**	**910,977**	**27,605**
				Lower CL	**567,481**	**17,196**
				Upper CL	**1,254,473**	**38,014**

Table A3. (Continued)

Watershed		Area (km^2)	Stream Order	Accessible Stream Length (m)	Habitat-Based Estimates	
					Average Smolts	Spawners
Georgia Strait – East Vancouver Island						
1	ANNIE CREEK	9	1	690	512	16
2	AYUM CREEK	14	3	630	463	14
3	BEACH CREEK	4	1	1,190	930	28
4	BECK CREEK	18	2	5,910	5,394	163
5	BLACK CREEK	65	4	45,570	59,173	1,740
6	BLOODS CREEK	2	1	210	139	4
7	BONELL CREEK	51	4	2,820	2,395	73
8	BONSALL CREEK	24	3	13,370	13,227	401
9	BROOKLYN CREEK	5	1	4,420	3,921	119
10	BUSH CREEK	28	2	1,740	1,410	43
11	CAMPBELL RIVER	72	7	10,250	9,877	299
12	CASEY CREEK	8	2	3,540	3,073	93
13	CHARTERS RIVER	19	4	700	520	16
14	CHASE RIVER	29	3	4,330	3,834	116
15	CHEF CREEK	8	3	6,250	5,736	174
16	CHEMAINUS RIVER	356	5	18,400	18,791	569
17	CLEAR CREEK	72	4	27,310	29,013	879
18	COLQUITZ RIVER	48	3	17,330	17,593	533
19	COOK CREEK	19	4	2,140	1,769	54
20	COWICHAN RIVER	672	7	391,830	289,869	8,784
21	COWIE CREEK	23	3	1,540	1,233	37
22	CRAIG CREEK	12	2	4,280	3,785	115
23	CRAIGFLOWER CREEK	23	3	4,340	3,843	116
24	DE MAMIEL CREEK	33	4	25,590	27,009	818
25	DEPARTURE CREEK	4	1	540	391	12
26	DOVE CREEK	43	3	22,500	23,444	710
27	DREW CREEK	3	1	2,460	2,061	62
28	ENGLISHMAN RIVER	316	6	59,120	44,592	2,230
29	FRENCH CREEK	70	4	10,780	10,440	316
30	FULFORD CREEK	21	3	4,910	4,401	133
31	GLENORA CREEK	22	4	14,330	14,275	433

Watershed		Area (km^2)	Stream Order	Accessible Stream Length (m)	Habitat-Based Estimates	
					Average Smolts	Spawners
Georgia Strait – East Vancouver Island						
32	GOLDSTREAM RIVER	58	4	4,840	4,332	131
33	HART CREEK	28	3	1,530	1,225	37
34	HASLAM CREEK	126	4	33,630	36,481	1,105
35	HEADQUARTERS CREEK	29	3	5,540	5,025	152
36	HOLDEN CREEK	23	3	9,190	8,761	265
37	HOLLAND CREEK	31	3	620	455	14
38	JORDAN RIVER	162	5	1,370	1,085	33
39	KELVIN CREEK	36	4	8,100	7,626	231
40	KINGFISHER CREEK	3	1	540	391	12
41	KIRBY CREEK	25	4	2,410	2,016	61
42	KITTY COLEMAN CREEK	13	3	13,230	13,075	396
43	KNARSTON CREEK	8	1	800	602	18
44	KOKSILAH RIVER	247	6	29,840	31,984	969
45	LANNON CREEK	3	2	990	760	23
46	LITTLE GEORGE CREEK	17	2	3,640	3,169	96
47	LITTLE OYSTER RIVER	38	3	39,760	43,864	1,329
48	LITTLE QUALICUM RIVER	252	4	32,120	34,683	1,051
49	LITTLE RIVER	19	3	17,080	11,767	357
50	MCKERCHER CREEK	16	3	6,310	5,797	176
51	MCNAUGHTON CREEK	9	3	2,490	2,089	63
52	MENZIES CREEK	24	4	4,680	4,175	127
53	MESACHIE CREEK	7	3	5,660	5,144	156
54	MILL STREAM	29	3	380	266	8
55	MILLARD CREEK	7	2	4,190	3,841	74
56	MILLSTONE RIVER	100	4	31,260	33,662	1,020
57	MOHUN CREEK	130	5	11,650	11,369	345
58	MORRISON CREEK	11	3	9,060	7,106	215
59	MUIR CREEK	66	5	2,830	2,404	73
60	NANAIMO RIVER	638	7	123,980	153,512	4,652
61	NANOOSE CREEK	34	3	3,090	2,647	80
62	NAPOLEON CREEK	3	2	3,760	3,283	99
63	NILE CREEK	16	3	6,180	5,666	172

					Habitat-Based Estimates	
	Watershed	Area (km^2)	Stream Order	Accessible Stream Length (m)	Average Smolts	Spawners
Georgia Strait – East Vancouver Island						
64	NORRIE CREEK	7	2	2,670	2,255	68
65	NORTH NANAIMO RIVER	62	4	38,860	42,772	1,296
66	NUNNS CREEK	6	2	4,170	3,678	111
67	OLIVER CREEK	5	4	3,820	3,341	101
68	OPEN BAY CREEK	12	2	6,350	5,837	177
69	OYSTER RIVER	324	6	28,600	30,524	925
70	PATRICIA CREEK	5	2	4,260	3,766	114
71	PORTER CREEK	4	1	230	154	5
72	PORTUGUESE CREEK	37	3	35,170	38,324	1,161
73	PUNTLEDGE RIVER	588	6	138,330	173,211	5,249
74	QUALICUM RIVER	146	5	12,730	12,533	380
75	QUINSAM RIVER	289	5	94,360	57,472	1,742
76	REAY CREEK	3	2	1,340	1,059	32
77	RICHARDS CREEK	21	3	18,230	18,600	564
78	ROBERTSON RIVER	99	5	29,860	32,007	970
79	ROCKY CREEK	7	3	450	320	10
80	ROSEWALL CREEK	44	4	4,480	3,980	121
81	ROY CREEK	13	2	6,170	5,656	171
82	SANDHILL CREEK	12	2	9,920	9,528	289
83	SANDY CREEK	3	1	2,070	1,706	52
84	SHAW CREEK	76	5	4,400	3,902	118
85	SIMMS CREEK	16	3	13,460	6,166	187
86	SOOKE RIVER	282	5	9,930	9,539	289
87	STOCKING CREEK	10	2	430	305	9
88	STORIE CREEK	5	2	5,760	5,244	159
89	SUTTON CREEK	44	4	9,670	9,265	281
90	TOD CREEK	24	3	160	103	3
91	TRENT RIVER	82	4	9,890	9,497	288
92	TSABLE RIVER	55	5	6,530	6,019	182
93	TSOLUM RIVER	158	5	92,380	31,802	964
94	TUGWELL CREEK	20	4	2,270	1,887	57
95	TYEE CREEK	12	2	410	289	9

Watershed		Area (km^2)	Stream Order	Accessible Stream Length (m)	Habitat-Based Estimates	
					Average Smolts	Spawners
Georgia Strait – East Vancouver Island						
96	WALKER CREEK	10	2	2,320	1,933	59
97	WATERLOO CREEK	8	3	1,780	1,542	67
98	WEXFORD CREEK	6	2	970	743	23
99	WHITEHOUSE CREEK	12	2	2,290	1,906	58
100	WILDWOOD CREEK	9	3	100	62	2
101	WILFRED CREEK	26	4	4,140	3,649	111
102	WILLOW CREEK	26	3	15,830	9,828	298
103	WOODS CREEK	11	3	9,960	1,441	80
			Subtotal	**1,764,520**	**1,603,226**	**49,422**
				Lower CL	**1,522,169**	**46,126**
				Upper CL	**1,684,282**	**51,039**

Watershed		Area (km^2)	Stream Order	Accessible Stream Length (m)	Habitat-Based Estimates	
					Average Smolts	Spawners
Howe Sound – Burrard Inlet						
1	ASHLU CREEK	343	5	5,860	5,344	162
2	BISHOP CREEK	7	4	120	76	2
3	BROHM RIVER	30	4	2,070	1,706	52
4	BROTHERS CREEK	9	2	430	305	9
5	CAPILANO RIVER	207	6	7,850	7,368	223
6	CHAPMAN CREEK	69	5	4,010	3,524	107
7	CHASTER CREEK	11	3	1,990	1,634	50
8	CHEAKAMUS RIVER	1,004	6	37,200	113,119	3,428
9	CHUK-CHUK CREEK	11	4	1,070	828	25
10	DAKOTA CREEK	33	5	850	643	19
11	DRYDEN CREEK	3	2	2,500	2,098	64
12	FRIES CREEK	20	4	280	191	6
13	HASTINGS CREEK	8	2	60	35	1
14	HOP RANCH CREEK	5	3	2,190	1,815	55
15	HUTCHINSON CREEK	5	2	370	259	8
16	INDIAN RIVER	193	5	20,170	20,788	630
17	JULY CREEK	10	3	560	407	12

	Watershed	Area (km^2)	Stream Order	Accessible Stream Length (m)	Habitat-Based Estimates	
					Average Smolts	Spawners
Howe Sound – Burrard Inlet						
18	LANGDALE CREEK	8	2	770	577	17
19	LOGGERS LANE CREEK	6	2	2,880	2,451	74
20	LYNN CREEK	51	5	6,590	6,080	184
21	MACKAY CREEK	7	3	3,350	2,893	88
22	MAMQUAM RIVER	337	6	10,590	10,238	310
23	MAPLEWOOD CREEK	4	2	230	154	5
24	MASHITER CREEK	41	4	660	487	15
25	MCCARTNEY CREEK	3	1	180	118	4
26	MCNAB CREEK	68	5	5,710	5,194	157
27	MCNAIR CREEK	20	5	730	544	16
28	MEIGHAN CREEK	4	2	1,850	1,508	46
29	MILL CREEK	41	4	390	274	8
30	MOSQUITO CREEK	14	3	4,260	3,766	114
31	MOSSOM CREEK	5	3	580	423	13
32	NOONS CREEK	5	3	650	479	15
33	OUILLET CREEK	6	3	530	383	12
34	PILLCHUCK CREEK	27	3	6,880	6,374	193
35	POTLATCH CREEK	28	4	370	259	8
36	RAINY RIVER	68	5	2,910	2,479	75
37	ROBERTS CREEK	29	3	430	305	9
38	SEYMOUR RIVER	178	5	30,210	71,139	2,156
39	SHANNON CREEK	15	4	550	399	12
40	SHOVELNOSE CREEK	18	4	370	259	8
41	SOUTH TWIN CREEK	6	2	250	168	5
42	SPRING CREEK	26	3	190	125	4
43	SQUAMISH RIVER	1,954	7	337,380	463,101	14,033
44	STAWAMUS RIVER	53	4	4,070	3,582	109
45	TERMINAL CREEK	9	3	5,970	5,455	165
46	WILSON CREEK	23	3	2,950	2,516	76
			Subtotal	**520,060**	**751,868**	**22,784**
				Lower CL	**557,442**	**16,892**
				Upper CL	**946,294**	**28,676**

Table A3. (Continued)

Watershed		Area (km^2)	Stream Order	Accessible Stream Length (m)	Habitat-Based Estimates	
					Average Smolts	Spawners
Boundary Bay						
1	CAMPBELL RIVER	72	7	67,440	78,483	2,378
2	MURRAY CREEK	28	4	27,630	29,387	891
3	NICOMEKL RIVER	153	4	201,290	261,945	7,938
4	SERPENTINE RIVER	144	4	184,720	238,267	7,220
			Subtotal	**481,080**	**608,082**	**18,427**
				Lower CL	**(102,001)**	**(3,091)**
				Upper CL	**1,318,165**	**39,944**

APPENDIX 4: SEP RELEASE DATA

Table A4. SEP release data by CU, life stage and brood year, 1990-2011.

CU	Life Stage	Brood Year	Escapement Year	Stream	Number Released	Fry:Smolt Survival	Fry:Adult Survival	Smolt:Adult Survival	ER	Total Enhanced Escapement
EVI-GS	Fed Fry	1987	1990	All	1,965,460	20%	-	6.0%	75.4%	5,839
EVI-GS	Fed Fry	1988	1991	All	2,078,201	20%	-	5.2%	67.9%	6,891
EVI-GS	Fed Fry	1989	1992	All	2,705,010	20%	-	5.9%	77.4%	7,180
EVI-GS	Fed Fry	1990	1993	All	2,214,953	-	0.9%	-	99.8%	48
EVI-GS	Fed Fry	1991	1994	All	2,627,858	-	0.7%	-	84.4%	2,960
EVI-GS	Fed Fry	1992	1995	All	2,071,832	-	0.8%	-	52.3%	8,113
EVI-GS	Fed Fry	1993	1996	All	2,696,550	-	0.3%	-	66.1%	3,095
EVI-GS	Fed Fry	1994	1997	All	1,862,977	-	0.8%	-	30.1%	10,713
EVI-GS	Fed Fry	1995	1998	All	2,169,004	-	0.2%	-	8.7%	3,651
EVI-GS	Fed Fry	1996	1999	All others	1,209,934	-	1.1%	-	5.5%	12,888
EVI-GS	Fed Fry	1996	1999	Area 17S	281,176	-	1.1%	-	5.5%	2,995
EVI-GS	Fed Fry	1997	2000	All others	941,473	-	0.5%	-	0.0%	4,560
EVI-GS	Fed Fry	1997	2000	Area 17S	781,915	-	0.5%	-	0.0%	3,787
EVI-GS	Fed Fry	1998	2001	All others	1,488,566	-	0.1%	-	0.0%	1,983
EVI-GS	Fed Fry	1998	2001	Area 17S	602,946	-	0.1%	-	0.0%	803
EVI-GS	Fed Fry	1999	2002	All others	1,122,215	-	0.5%	-	7.4%	5,359
EVI-GS	Fed Fry	1999	2002	Area 17S	507,424	-	0.5%	-	7.4%	2,423
EVI-GS	Fed Fry	2000	2003	All others	1,661,044	-	0.2%	-	0.0%	2,974
EVI-GS	Fed Fry	2000	2003	Area 17S	372,346	-	0.2%	-	0.0%	667
EVI-GS	Fed Fry	2001	2004	All others	1,247,494	20%	-	1.5%	23.2%	2,808
EVI-GS	Fed Fry	2001	2004	Area 17S	181,863	20%	-	2.2%	28.9%	558

CU	Life Stage	Brood Year	Escapement Year	Stream	Number Released	Fry:Smolt Survival	Fry:Adult Survival	Smolt:Adult Survival	ER	Total Enhanced Escapement
EVI-GS	Fed Fry	2002	2005	All others	1,119,386	20%	-	0.3%	23.8%	505
EVI-GS	Fed Fry	2002	2005	Area 17S	178,482	20%	-	1.0%	90.4%	35
EVI-GS	Fed Fry	2003	2006	All others	1,222,229	20%	-	0.2%	19.6%	341
EVI-GS	Fed Fry	2003	2006	Area 17S	261,592	20%	-	0.2%	19.6%	73
EVI-GS	Fed Fry	2004	2007	All others	1,159,450	20%	-	0.8%	38.3%	1,130
EVI-GS	Fed Fry	2004	2007	Area 17S	113,730	20%	-	0.8%	83.6%	30